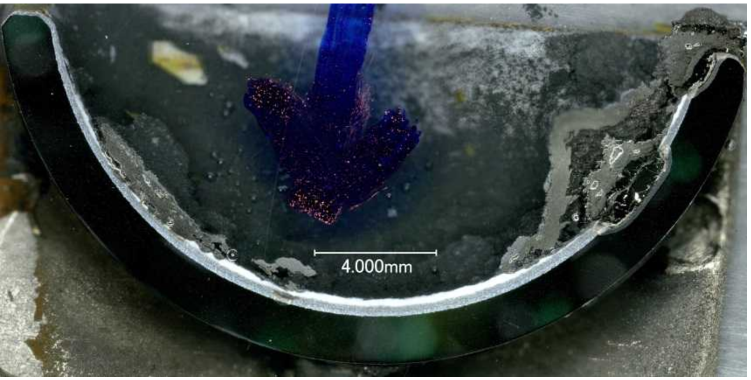
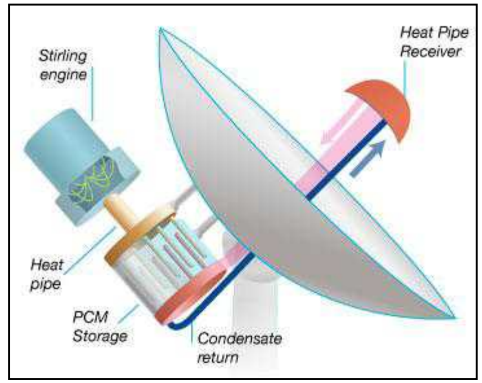
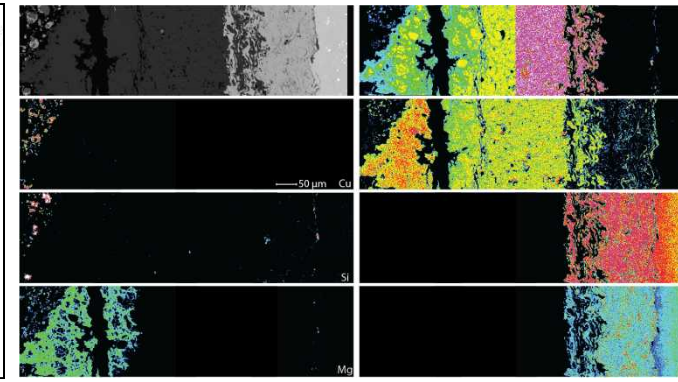
Exceptional service in the national interest

SAND2015-1547C

Sandia National Laboratories







Materials Compatibility In Dish-Stirling Solar Generators Using Cu-Si-Mg Eutectic for Latent Heat Storage

Liz Withey, Alan Kruizenga, and Charles Andraka

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Introduction

Goal: demonstrate the feasibility of significant thermal storage for dish Stirling systems to

- Meet SunShot cost goal of 6-8 ¢/kWh
- Provide feasible technical solution for 6 hours of storage on large (25kWe) system
- Enable high performance Dish-Stirling systems to increase capacity into evening hours

Achieved through:

- Improved system performance
- Lower levelized cost of energy (LCOE)
- Reduced system cost through more efficient structural design
- Focus on “on-dish” high temperature PCM storage

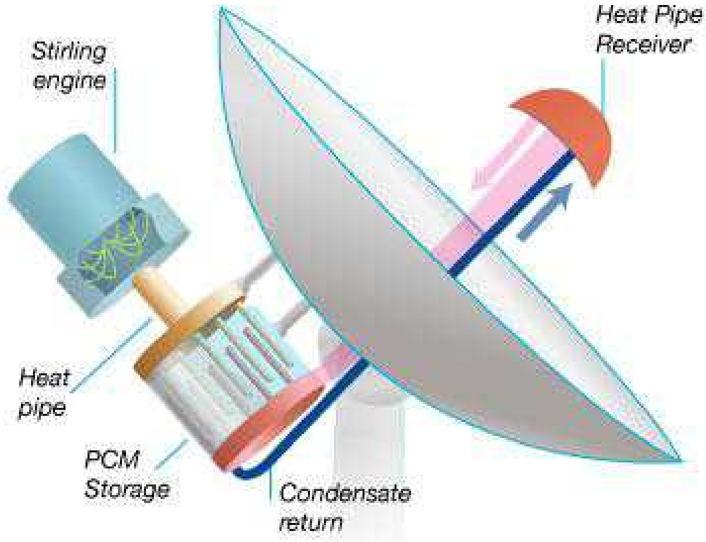
Background

Current design of dish-engine systems lack heat storage to allow for energy production in low/no light conditions

- Addition of storage not easily accommodated at the end of dish boom
- Long-term storage requires a large amount of storage media

Sandia approach enables storage and engine mounting on the rear of dish

- Facilitates larger thermal storage mass (≥ 6hrs)
- Closed pedestal gap allowing efficient structure
- Near isothermal and isothermal heat pipes transport energy to and from storage media (developed at Sandia/DOE)



Objective: Test compatibility of chosen phase change material with Haynes 230 containment alloy

Sandia National Laboratories

SELECTION CRITERIA

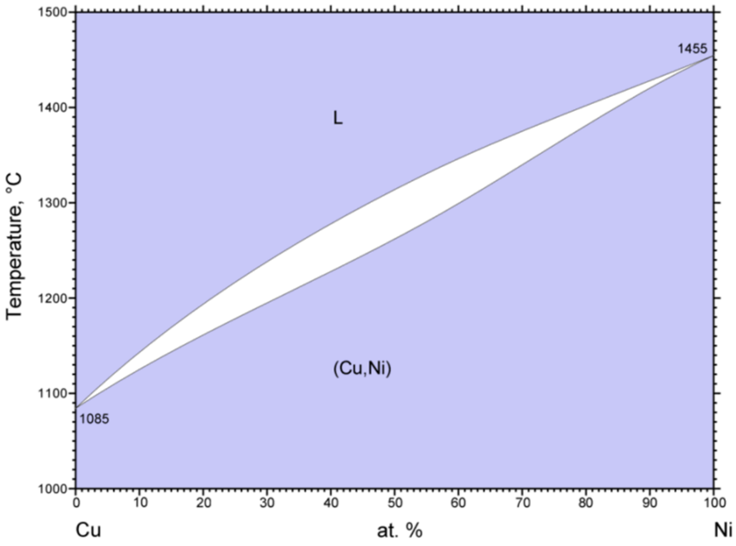
- Melting temperature between 750-800 °C to match Stirling cycle
- Large latent heat of melting for high energy density (mass of PCM needed)
- Good thermal conductivity (esp. in solid phase)
- Material compatibility with containment material
- Low vapor pressure (containment issues)
- Small volume change to minimize voids in solid phase on discharging
- Chemical stability
- Cost

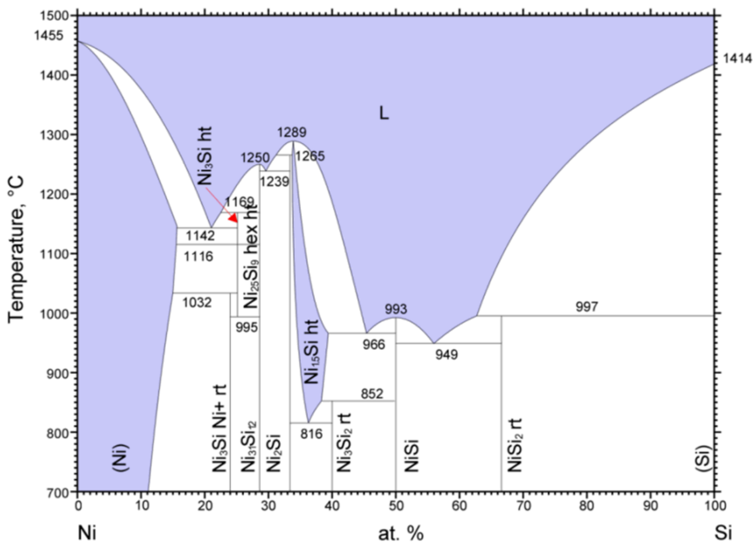
⇒ **METALLIC PCM**

PCM	T_M (°C)	ΔH (J/g)	k_{solid} (W/mK)
CuSiMg	742	548	200
CuSi	802	267	300
NaCl	801	482	1.59

53.5 Cu-25.34 Si-21.16 Mg (wt%)

Containment Material



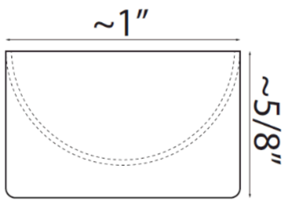


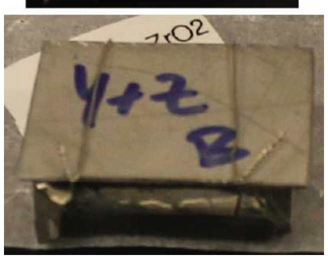
Haynes 230: Ni-superalloy

- Ni-22Cr-14W-2Mo-0.5Mn-0.4Si-0.3Al-0.1C-0.02La-max(5Co-3Fe-0.015B) (by wt.)
- Chosen for compatibility with high T heat pipe, and high T mechanical properties

Compatibility Issues with Hayne 230: Cu and Si readily dissolve to at least some extent in Ni indicating likely

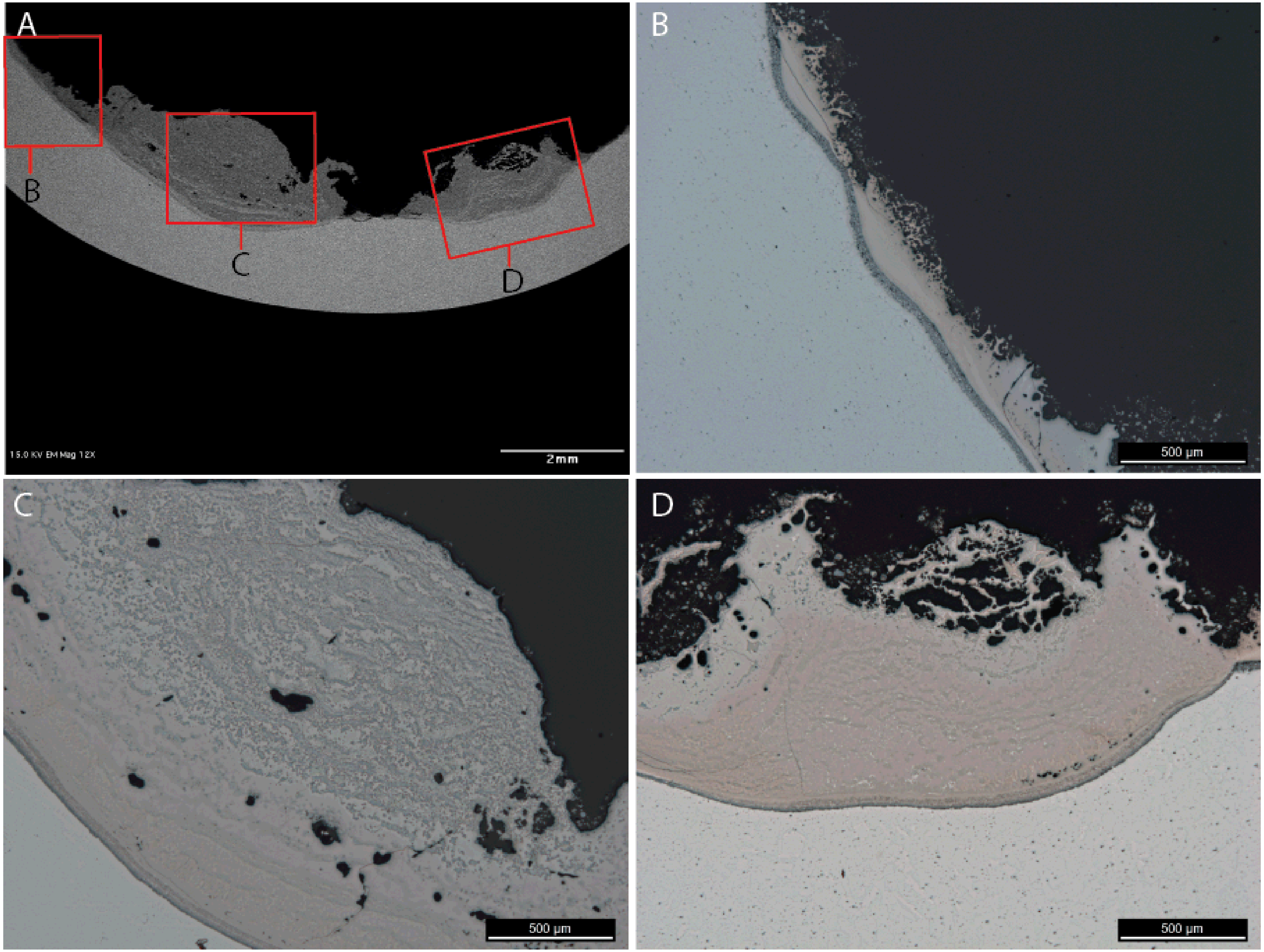
Experiment



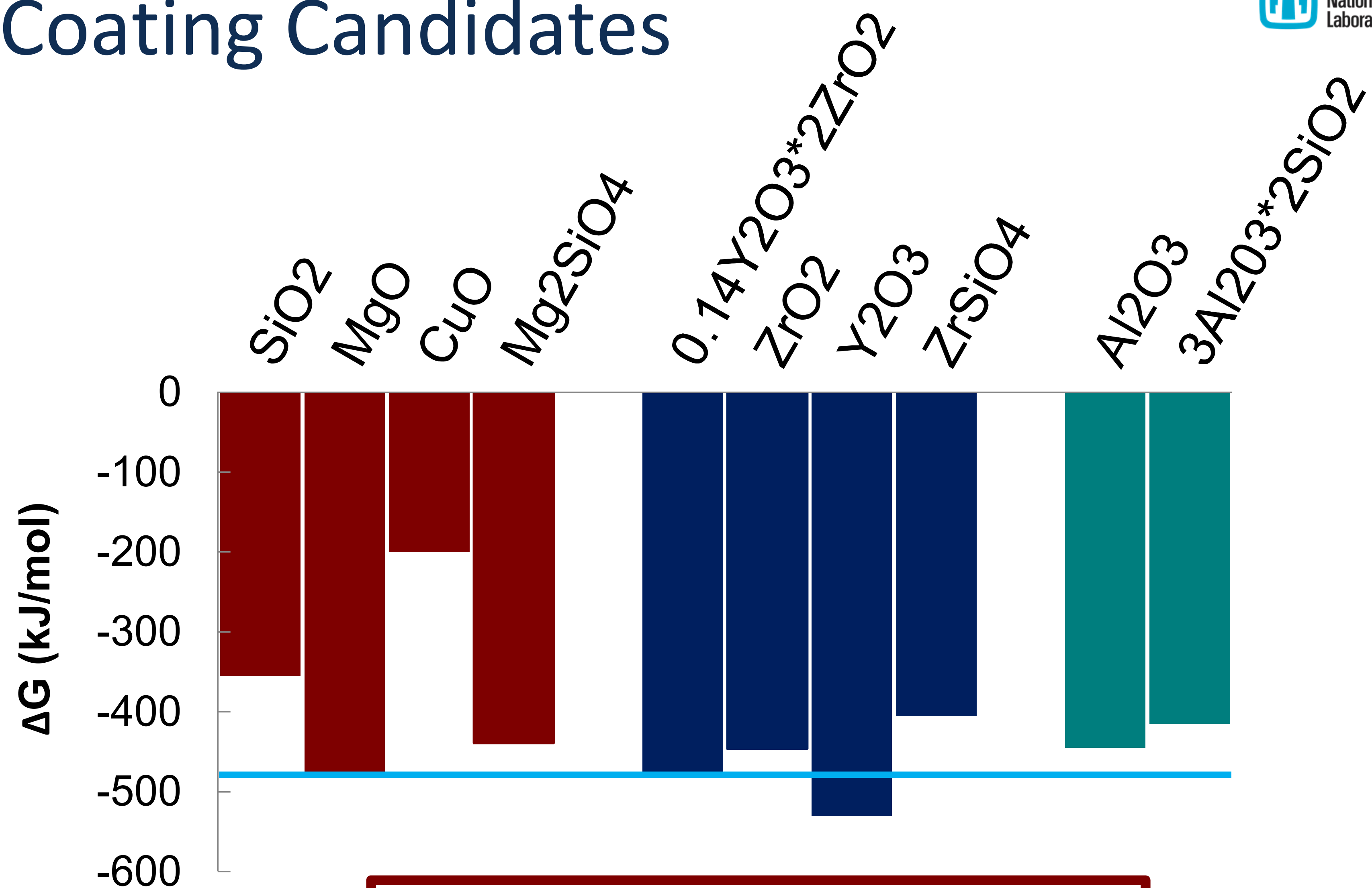


1. Boats ground to fit capsule and remove corners
2. Filled with 3g PCM powder
3. Wire on lid to contain PCM during capsule sealing
4. Sealed in quartz capsule back-filled with 200 Torr Ar
5. Heated to 820 °C for 150 and 500 hrs in furnace and air cooled
6. Unsealed (in Ar atmosphere), loose PCM removed and saved for analysis
7. Boat potted in resin for cross-sectional metallography
8. Optical microscopy
9. Several boats chosen for further characterization with electron microscopy

Haynes 230 (150hr at 820 °C)



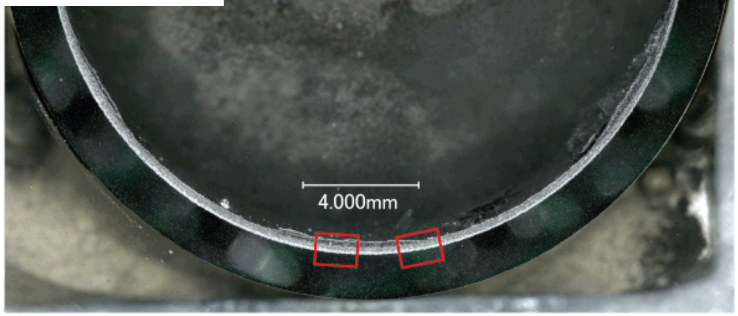
Coating Candidates



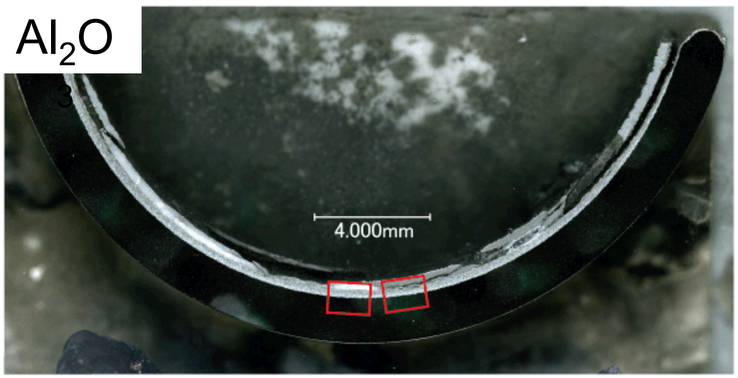
Al_2O_3, 20%YSZ, Y_2O_3

150hr Results

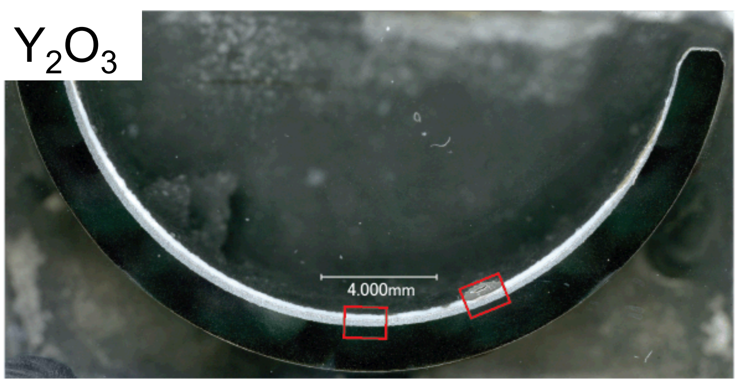
20%YSZ

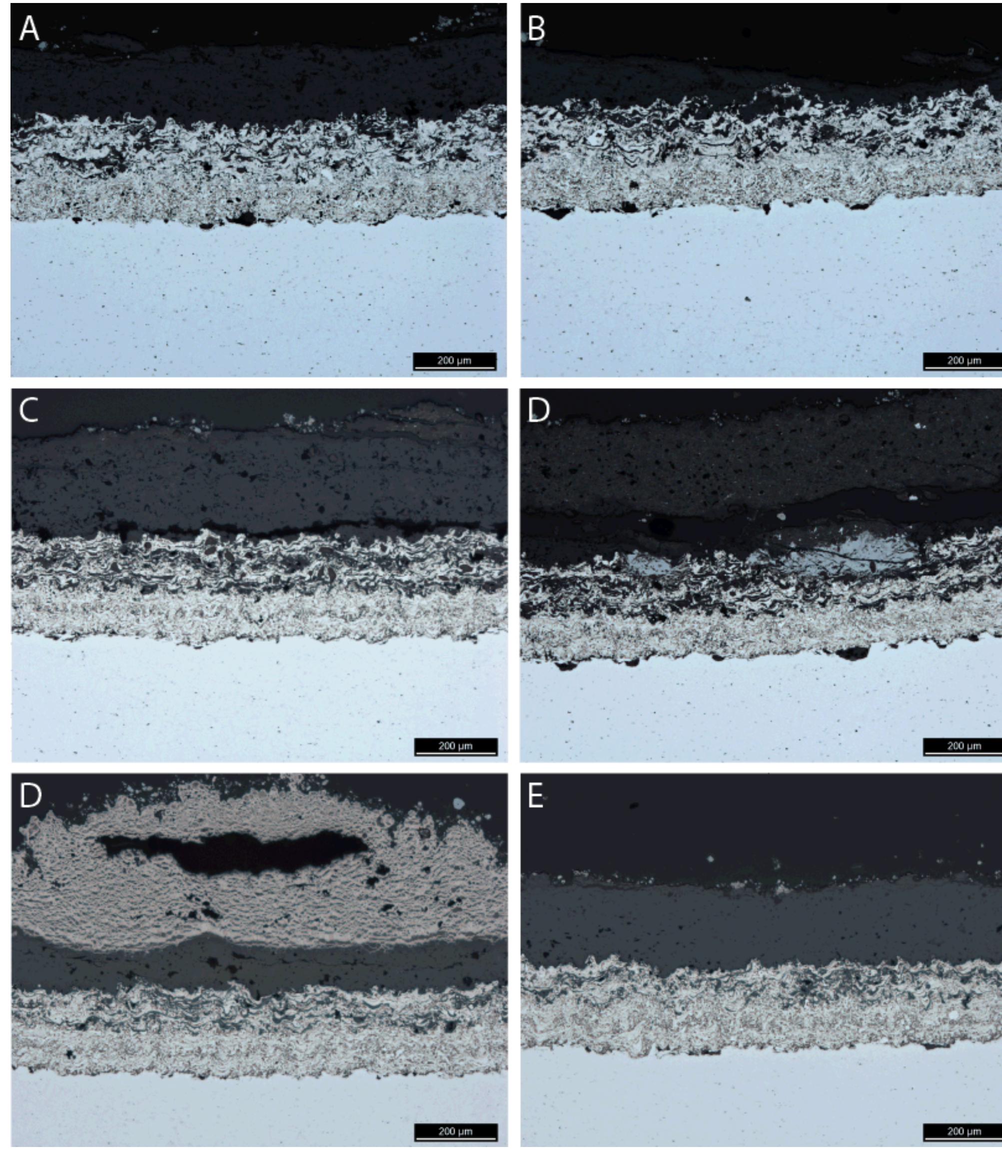


Al_2O_3

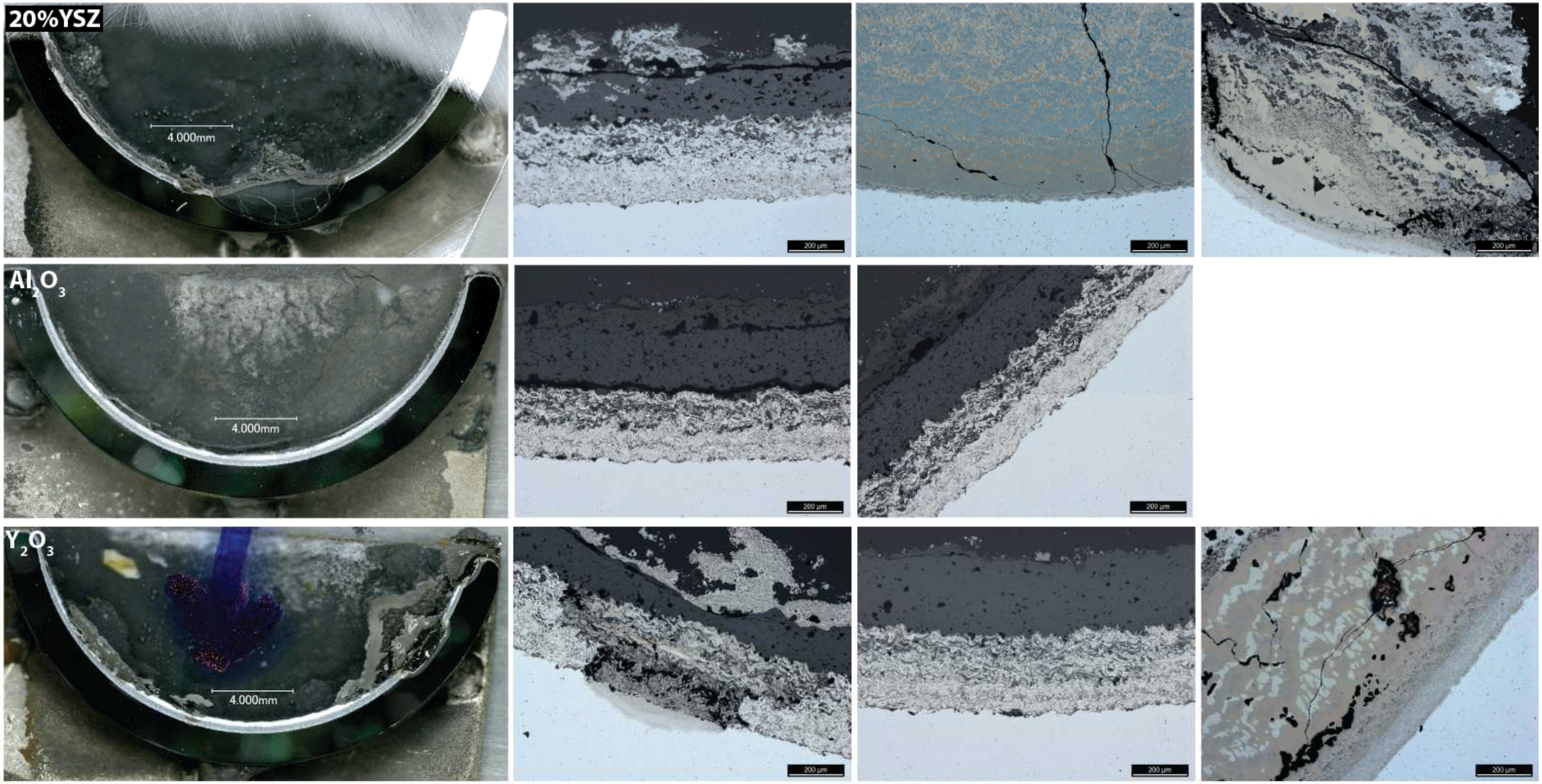


Y_2O_3

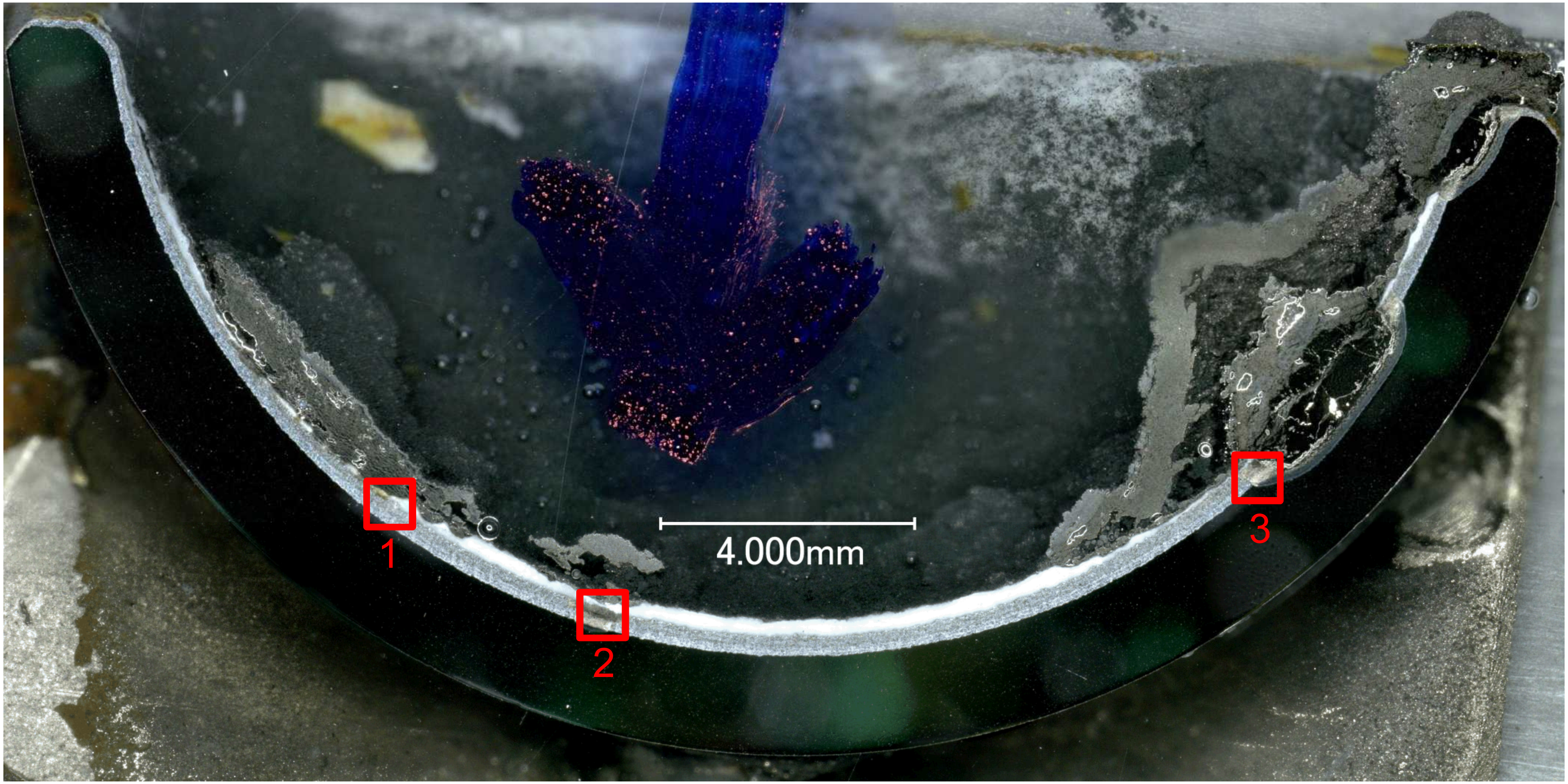




500hr Results

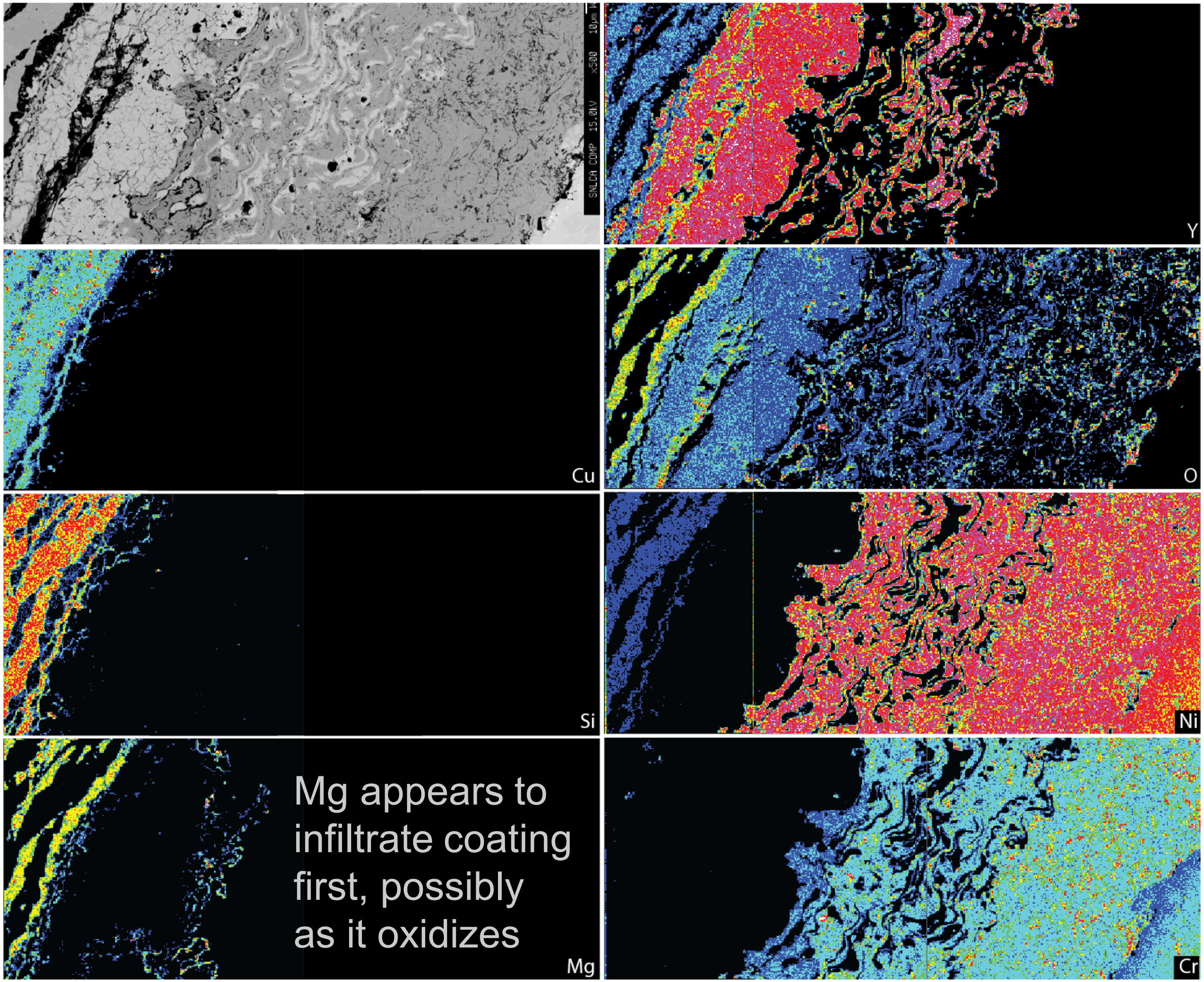


Process of Failure: Y_2O_3



Electron microprobe of areas of varying degrees of attack

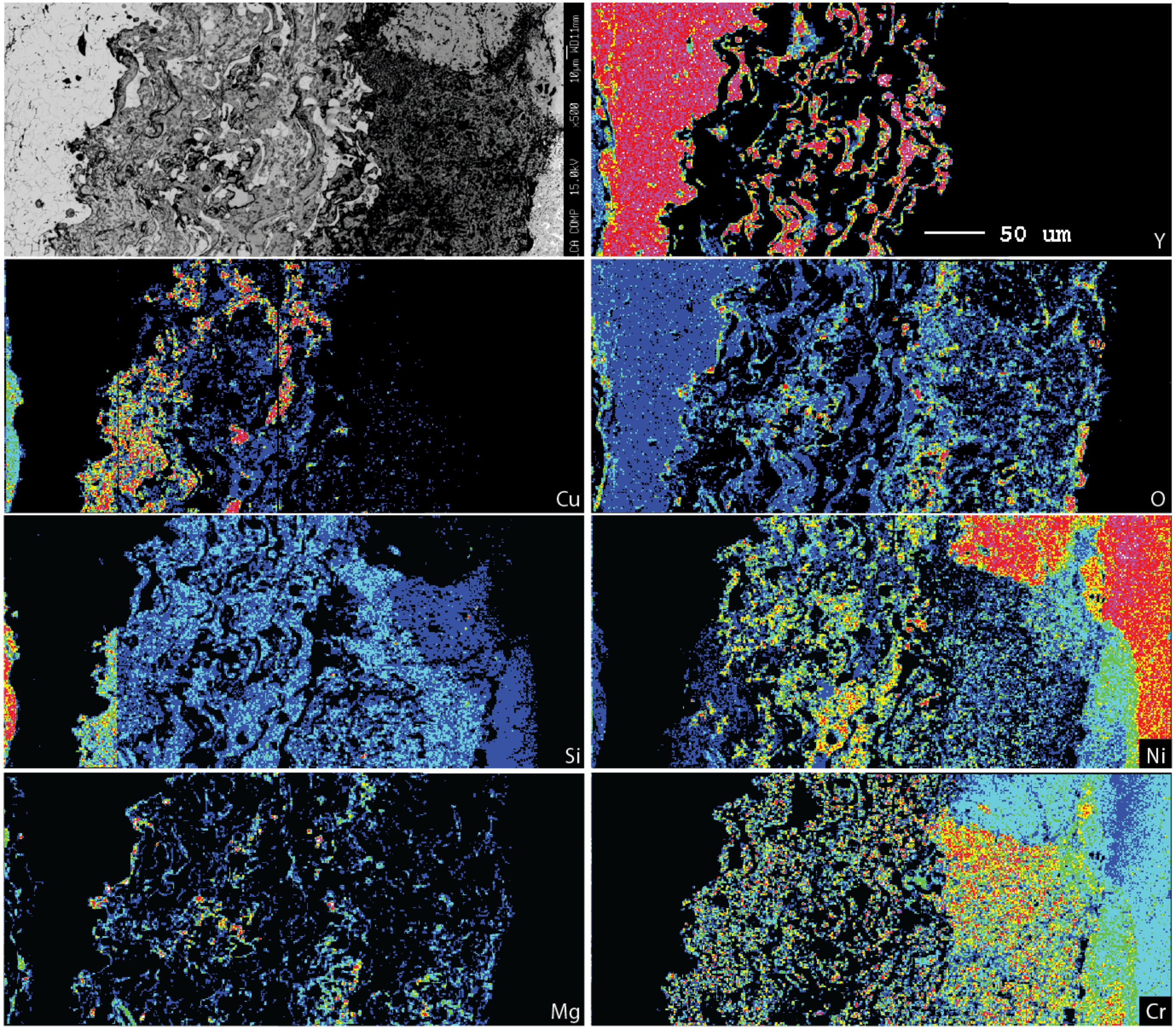
Y_2O_3 Area 1: Beginning of interaction



Coating structure = 80Ni/20Cr + graded 80Ni/20Cr & Y2O3 + Y2O3

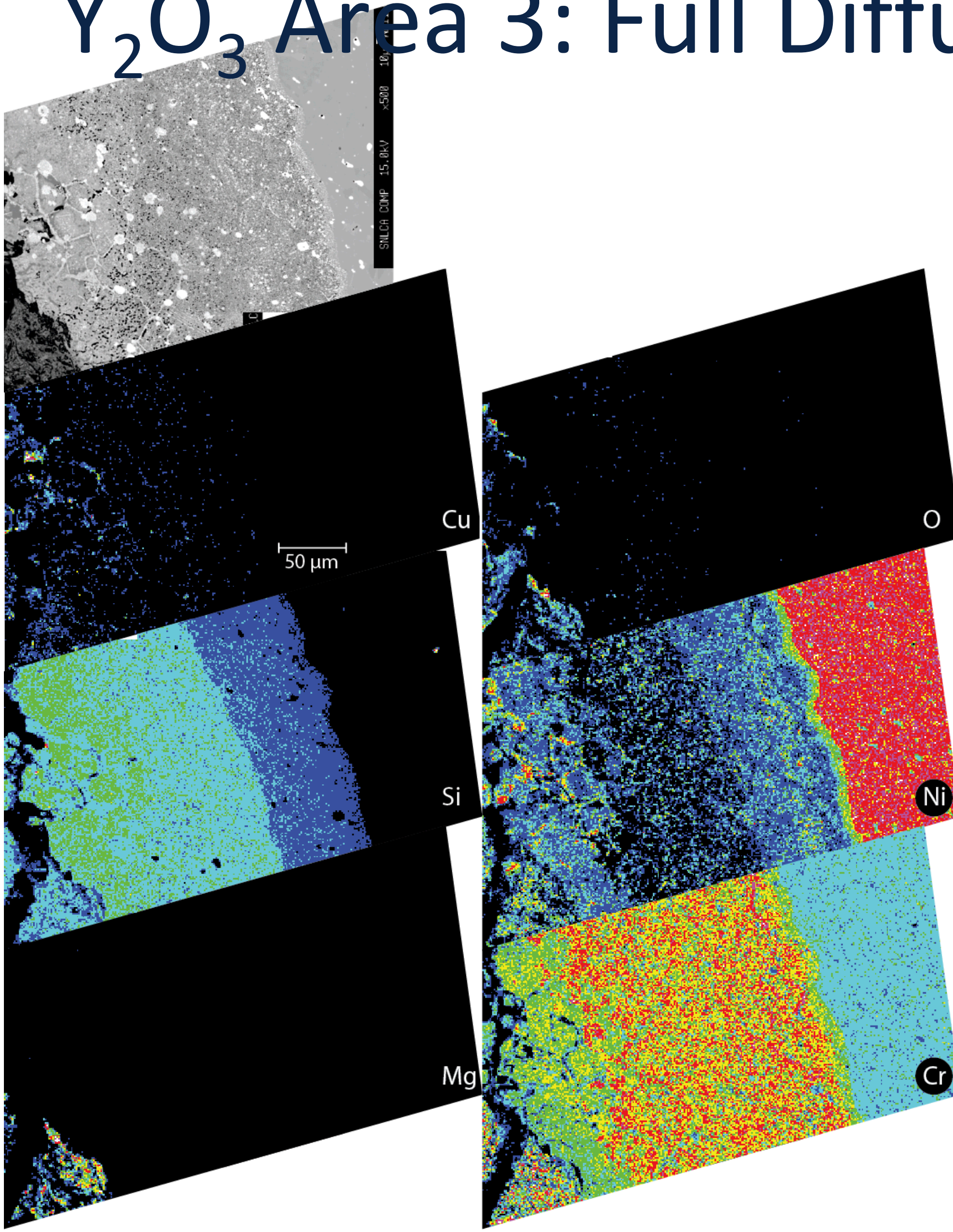
Y_2O_3 Area 2: Early Diffusion Layer

In areas of further attack, Si more invasive than Mg



Y_2O_3 Area 3: Full Diffusion Layer

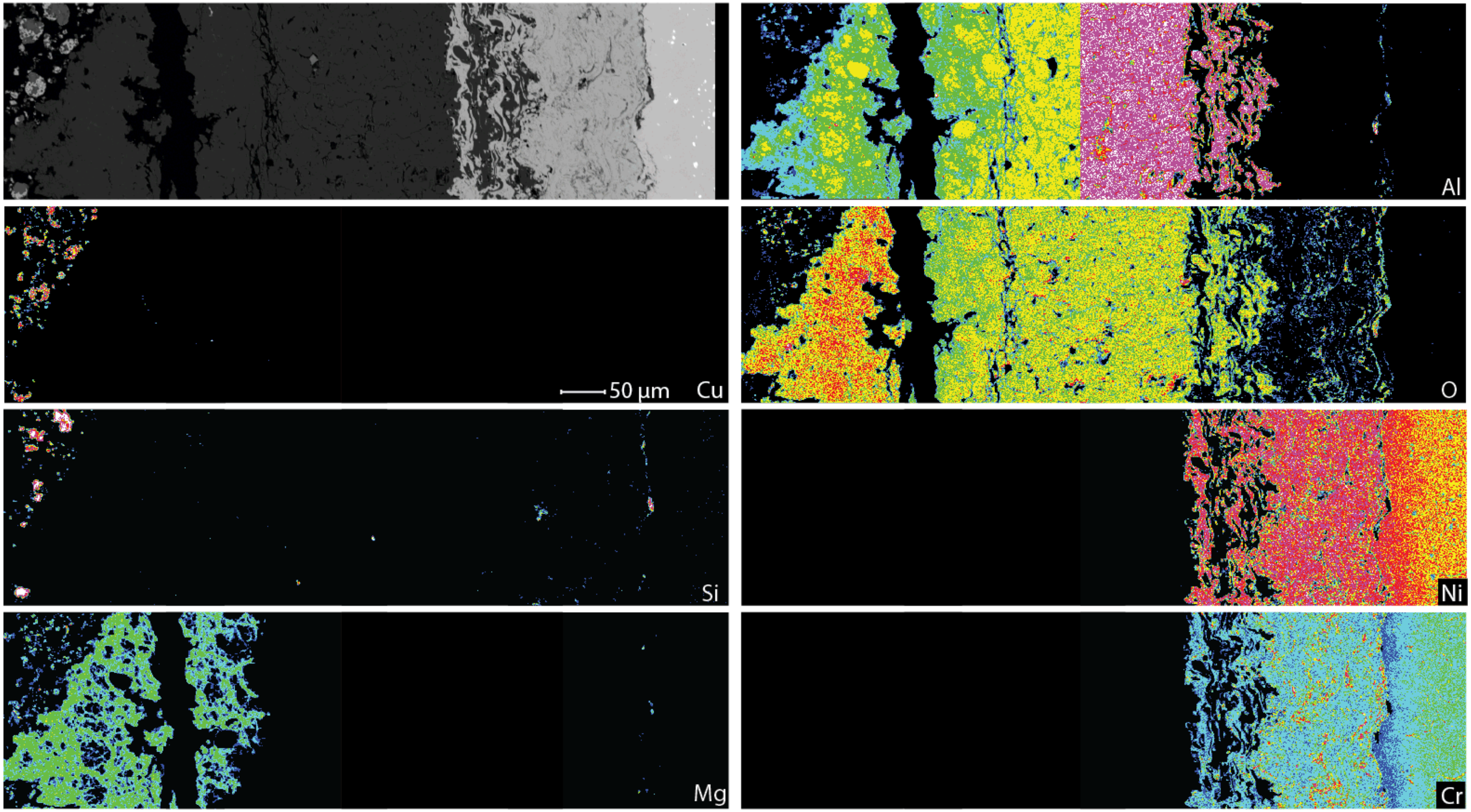
Sandia National Laboratories



Tentative Conclusion:
Mg infiltrates Y_2O_3 as it oxidizes and leaves easy pathway for Si infiltration

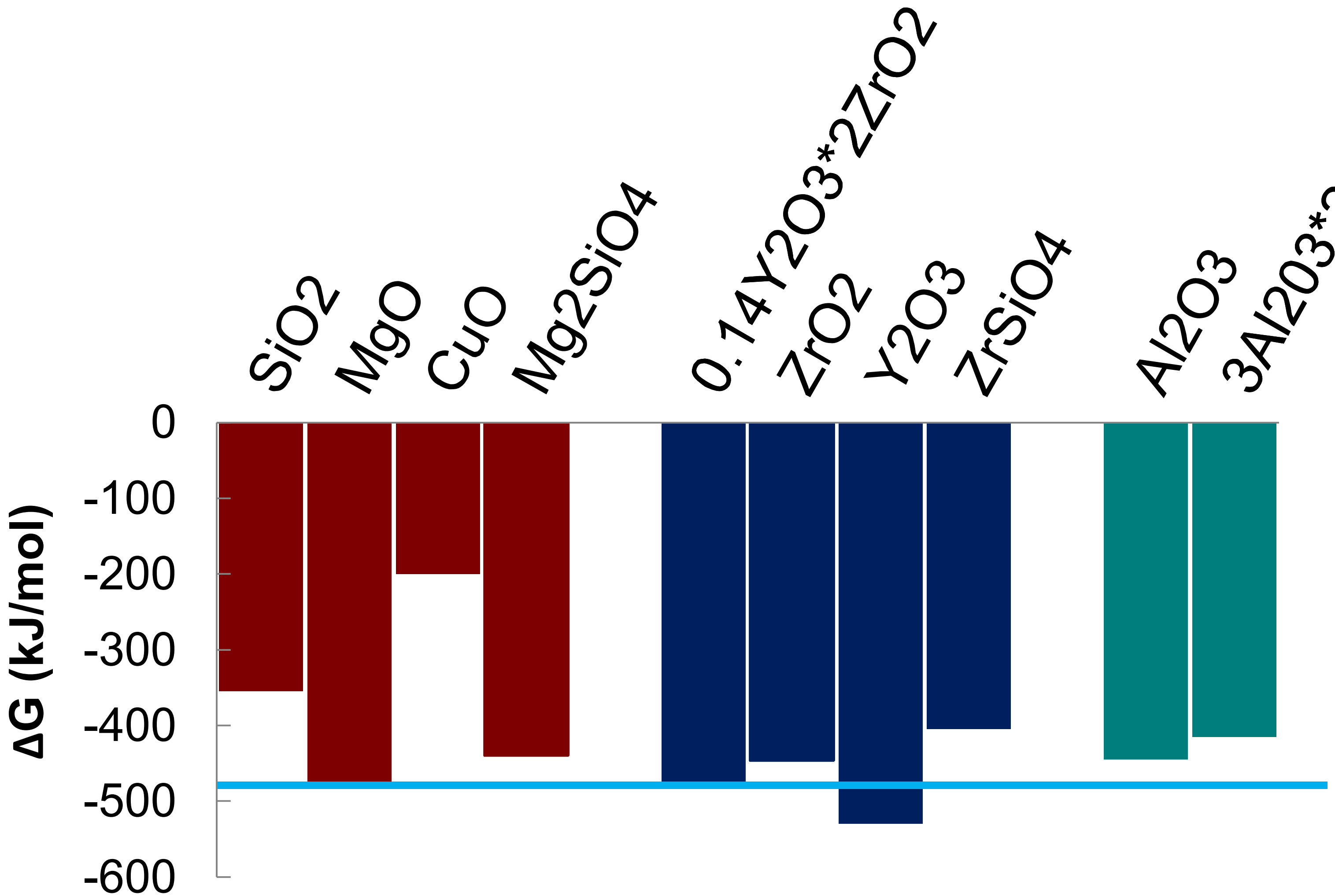
- Y2O3 + 3Mg → 3MgO + 2Y will result in equilibrium amount of MgO since low driving force in either direction
- Conversion Y2O3 to MgO results in open porosity for Si easily infiltrate and attack Haynes 230

Surface Film on Al_2O_3 Coating



Mg reacts with Al_2O_3 to form compound oxide, most likely $MgAl_2O_4$

Thermodynamics and Coating Success



Thermodynamics not always best prediction when kinetics unknown.

Conclusions

- As expected, Haynes 230 is severely attacked by PCM
- 20%YSZ, Al_2O_3, and Y_2O_3 appear to protect Haynes 230 from liquid metal attack after 150hrs, but 20%YSZ and Y_2O_3 fail after 500 hrs
- Al_2O_3 protects Haynes 230 for up to 500 hrs by forming $MgAl_2O_4$

Thanks

Alan Kruizenga
Charles Andraka
Andrew Gardea
Ryan Nishimoto