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Ceramics Expo 2026: Joining and Fabrication of Nuclear Cladding and Ceramic Matrix Composite Materials Through Embedded Wire Chemical Vapor Deposition

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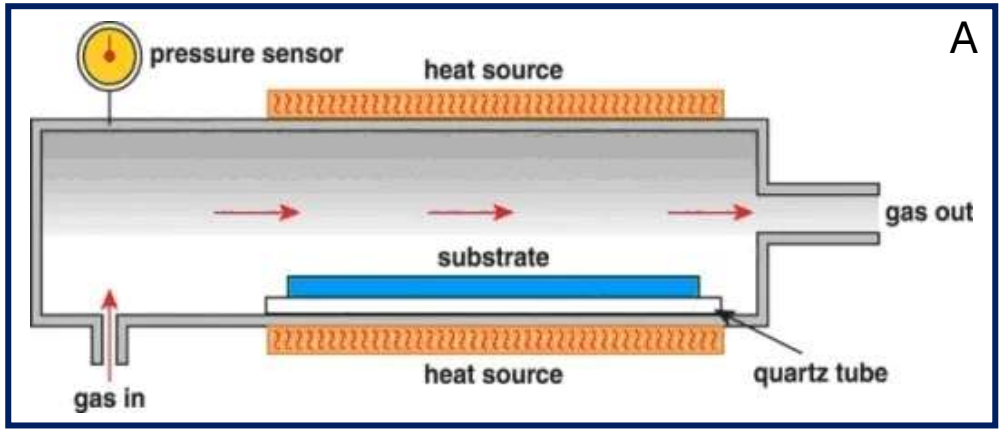
Presentation Overview

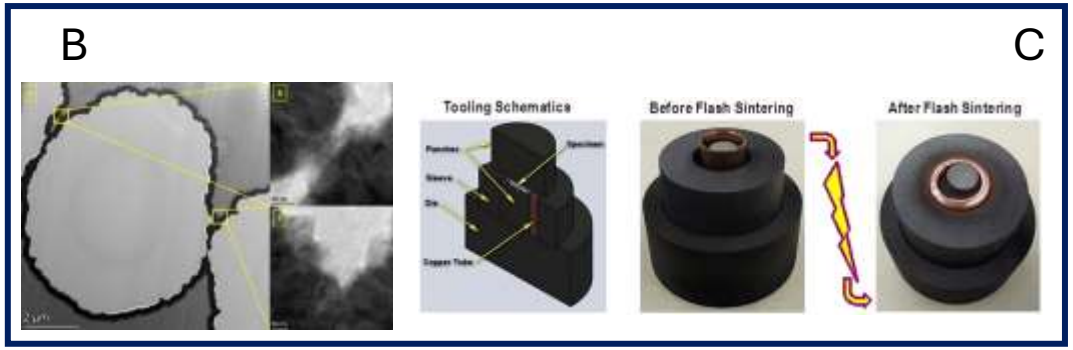
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- What is embedded wire chemical vapor deposition (EW-CVD):
  - Fabrication origins
  - Joining and unique shape generation
- End use cases for embedded wire chemical vapor deposition:
  - Joining and fabrication of non-oxide ceramic matrix composites (CMCs)
  - Joining and coverage of nuclear cladding-based materials
- Future uses and conclusions

EW-CVD introduction: Landscape of CVD in CMC manufacturing

- Chemical vapor deposition:
  - Underutilized in manufacturing
  - Difficulties in modeling
  - Sintering, MI, and PIP methodologies preferred
- Advantages of the CVD process:
  - Near stoichiometric coatings
  - Excellent control of morphology
  - Complex shape creation
  - Excellent interfacial coating bonding strength
- FFF goal with EW-CVD:
  - Leverage CVD benefits to join and manufacture CMCs

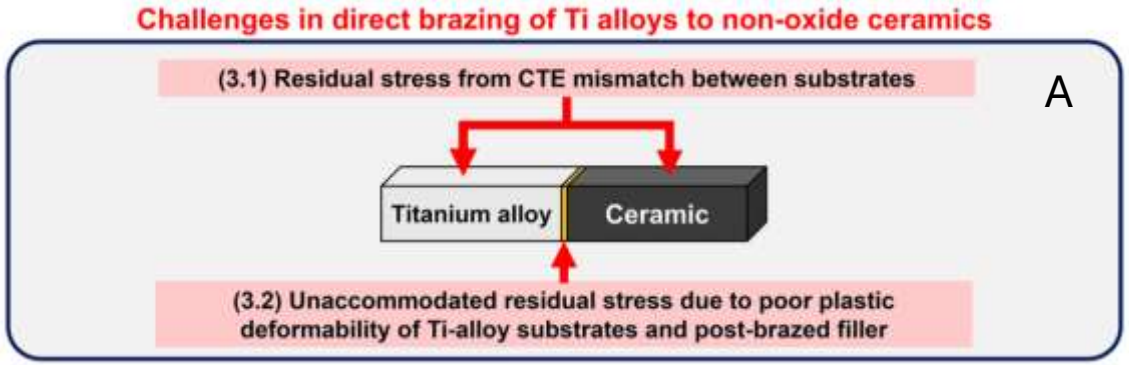


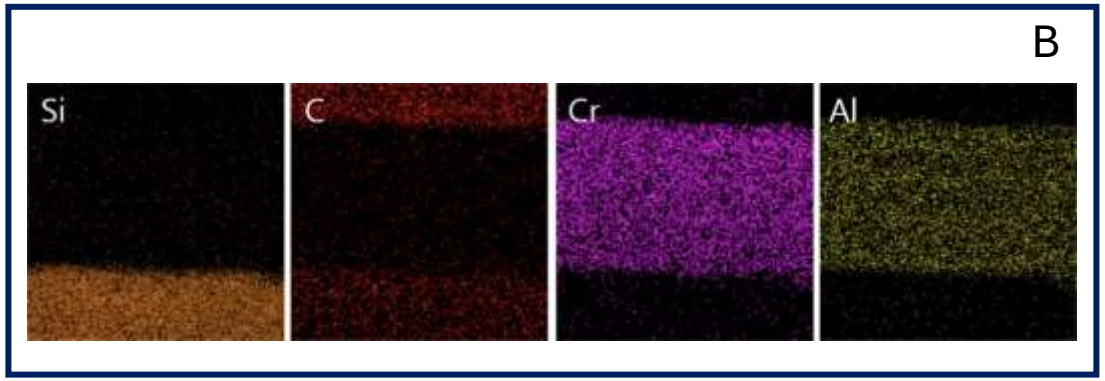


A: Diagram of a horizontal CVD reactor
B: CVD derived TiC interfacial coating (Wickramathilaka et al.)
C: Limitation of sintering geometries (Olevsky et al.)

EW-CVD Introduction: Joining of non-oxide ceramics and CMCs

- Joining of CMCs: Less mature than other techniques
  - CTE mismatch
  - Interfacial reactions
  - Oxidation susceptibility
- Currently used techniques:
  - Metal brazing methodologies
  - Diffusion bonding (limited geometries)
  - Molten Si reaction bonding (damage to exposed reinforcing components)





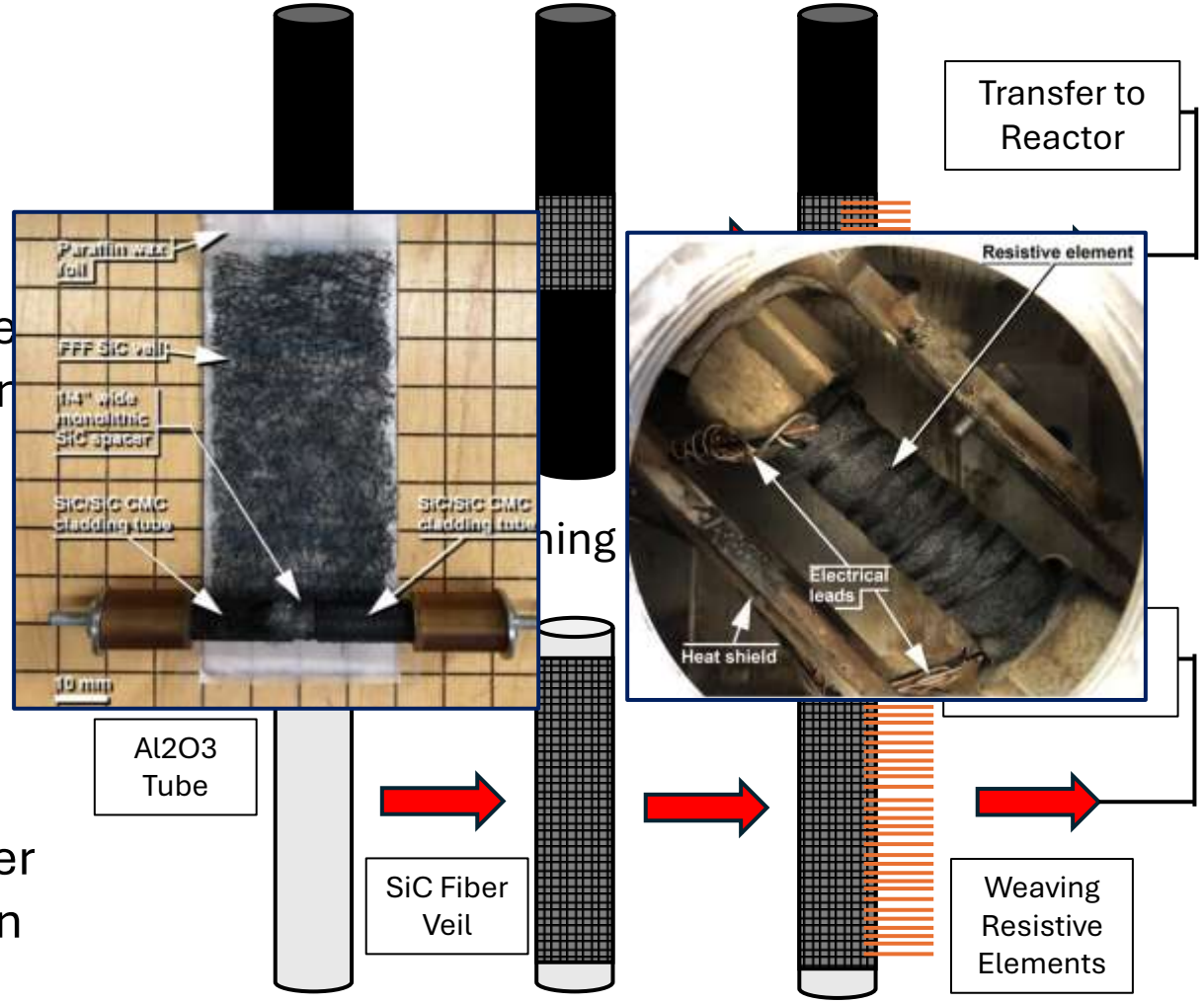
A: Brazing approach for a Ti non-oxide ceramic joining system (ong et al.)
B: Complex alloy system for joining SiC (Lee et al.)

Embedded Wire Chemical Vapor Deposition: Fabrication procedure

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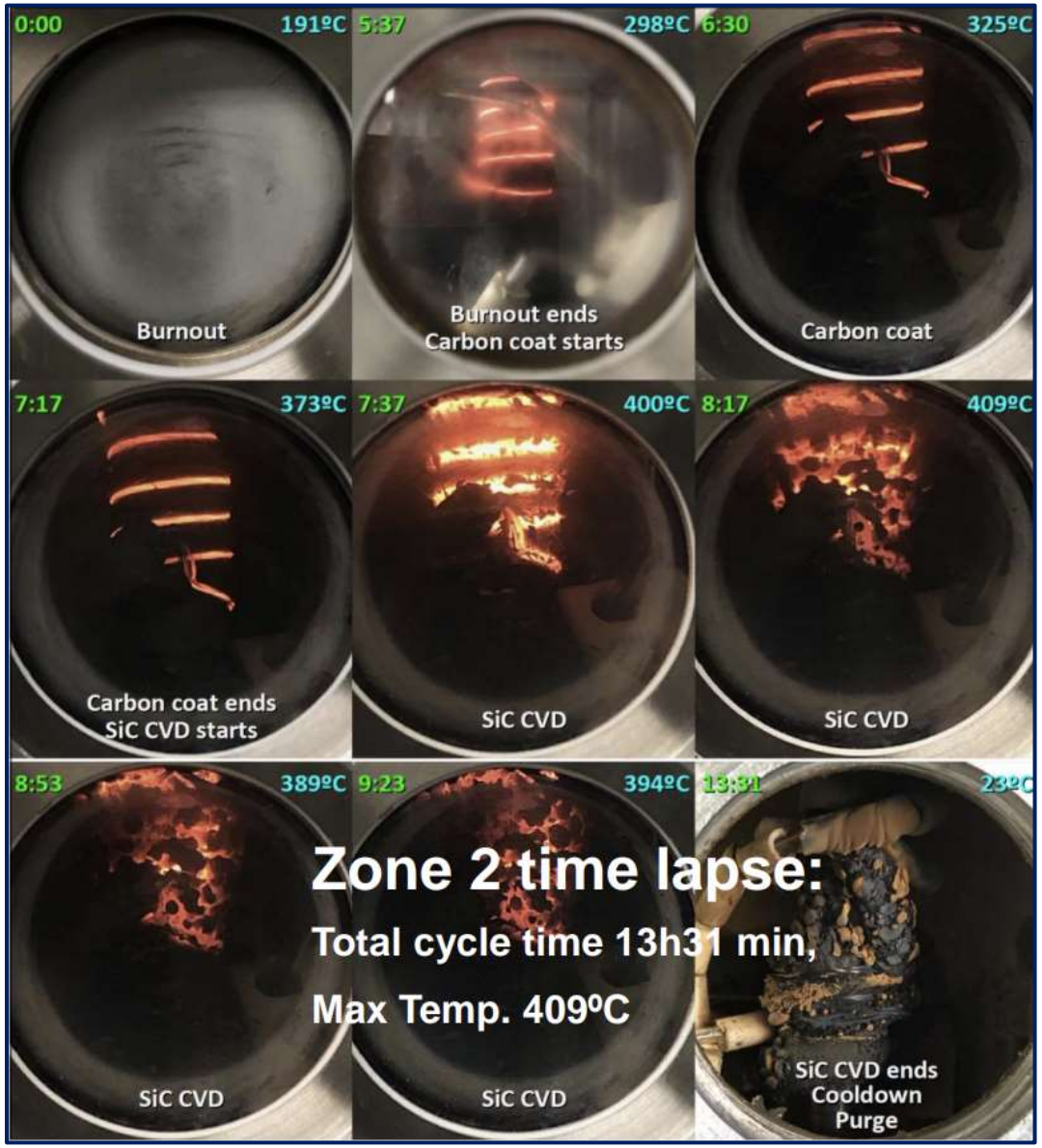
- Joining:
  - Two materials pinned together
  - Wrapped with SiC fiber veils from FFF
  - Wrapped over and woven in resistive elements
  - Resistive elements connected to an external powe supply while sample is contained within a reactior chamber

- Infiltration:
  - Layers of SiC veils wrapped around each other (or material)
  - Interwoven resistive elements
  - Resistive elements connected to an external power supply while sample is contained within a reaction chamber



General Infiltration (Free Standing CMCs) Schematic

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General reaction parameters

- Burnout (residual oxygen)
- Deposition of interfacial coatings
- Deposition of matrix and joining section
- Power acts as a temperature proxy
- Joining: 10-40 hours
- Freestanding CMC: 50-100 hours

Nuclear Cladding Joining Efforts

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- Experiments conducted joining SiC/SiC CMCs to nuclear cladding tubes (Zr)
- Power densities 150 W/inch sample
- XCT shows joining estimates at 7.9 % - 23. 8 % porosity
  - Limitations of chosen parameters not EW-CVD as a whole



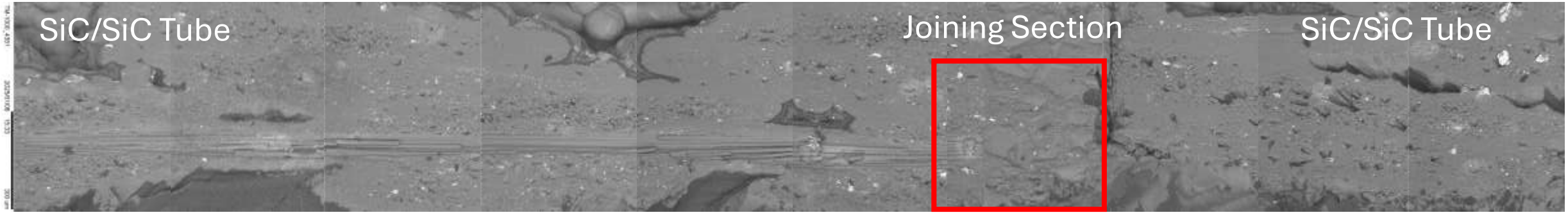
Zr-SiC/SiC Hybrid Joining

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Silicon Carbide CMC Joining Efforts

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- Joining of SiC CMCs tubes (“1 long) provided to FFF by ORNL
- Power densities: 150 W/Inch sample
- Joining time: 50 hours
- XCT shows joining estimates at 7.9 % - 23. 8 % porosity
  - Limitations of chosen parameters not EW-CVD as a whole



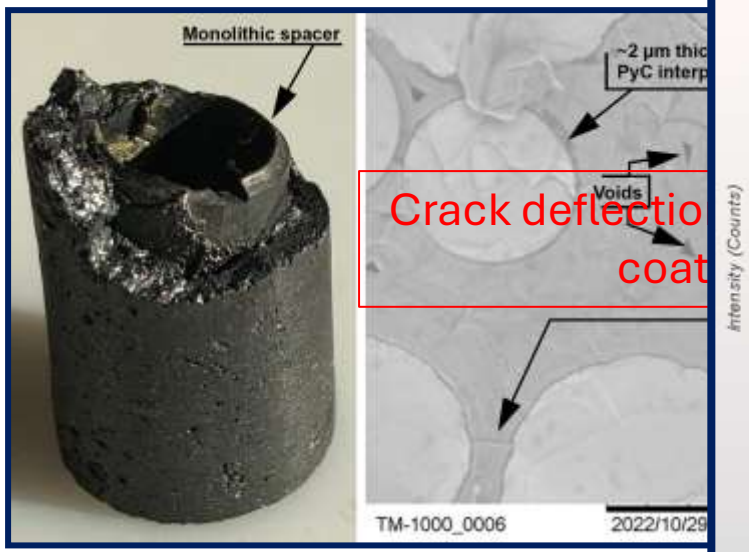
SiC/SiC Joining

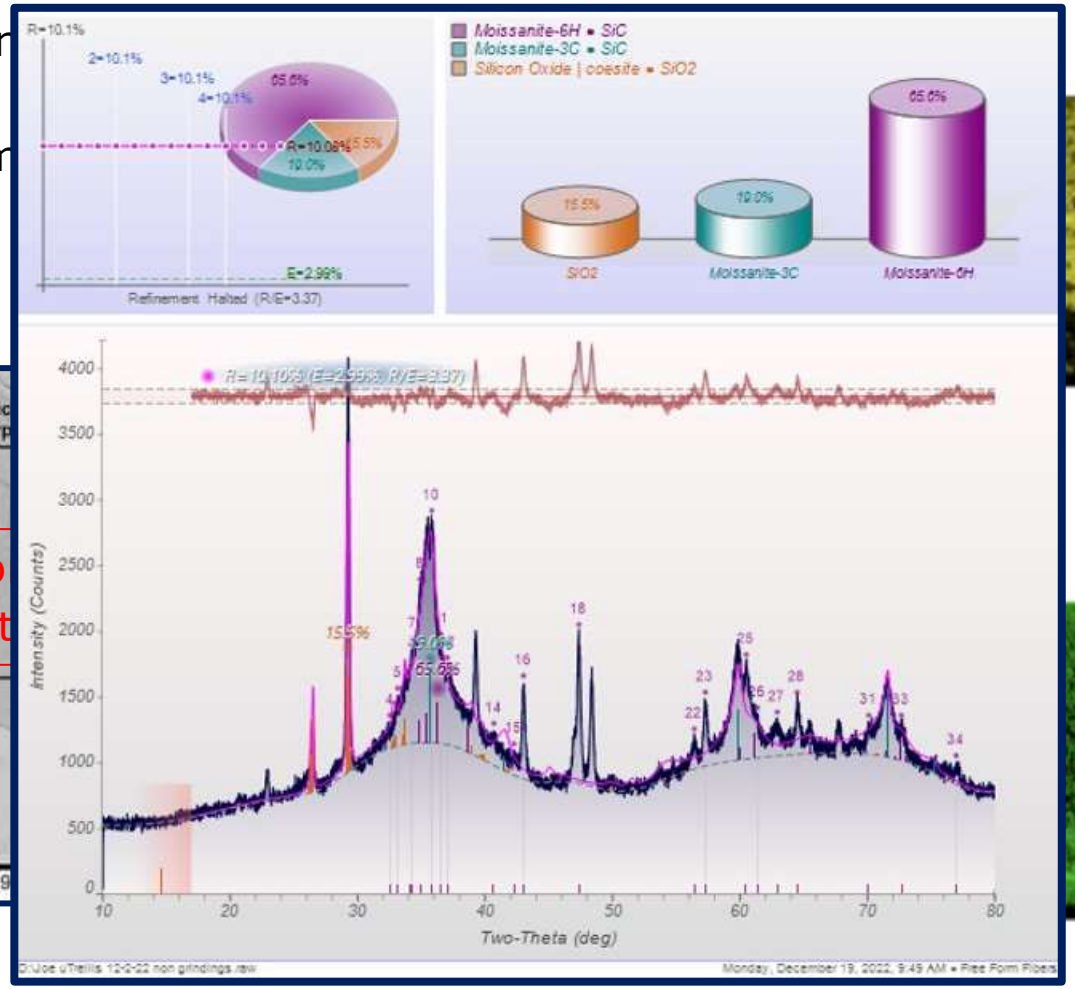
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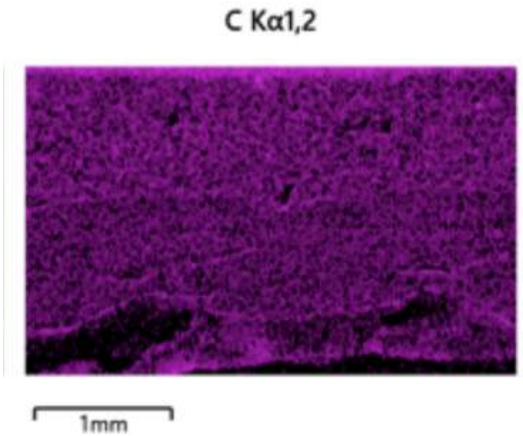
Embedded Wire Chemical Vapor Deposition: Characterization Efforts

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- Joining of SiC CMCs tubes (“1 lon
- Power densities: 150 W/Inch sam
- Joining time: 50 hours







EDX Mapping:

Homogenous display of C, Si

O presence attributed to machining

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Conclusions

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- Embedded Wire Chemical Vapor Deposition (EW-CVD)
  - Demonstrates a unique methodology for the joining of high temp materials
    - Nuclear cladding materials
    - SiC/SiC CMCs
  - Fabrication of full free-standing CMCs
    - SiC CMCs
  - Impressive densification metrics
  - High materials purity (SEM-EDS, XRD)
  - Low power density requirements
  - Control over thermal gradients

Future Work

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- Expansion into different materials (proven on lab-scale basis)
  - Si_3N_4
  - Py-Carbon
- Increased reactor size
  - Different part geometries
  - Improved turnaround
- Increased characterization efforts
  - TEM investigations
  - Mechanical testing

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Comments?

Questions?

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