Ceramic, Composite and Optical Materials Center

Arc Melting: A Route for High-Temperature Ceramic Composites, Doping, and Powder Synthesis

Core faculty:	Richard A. Haber
Research associate:	Chawon Hwang & Jun Du
Graduate student:	Qirong "Bruce" Yang

Jan 30th, 2019

CCOMC Meeting

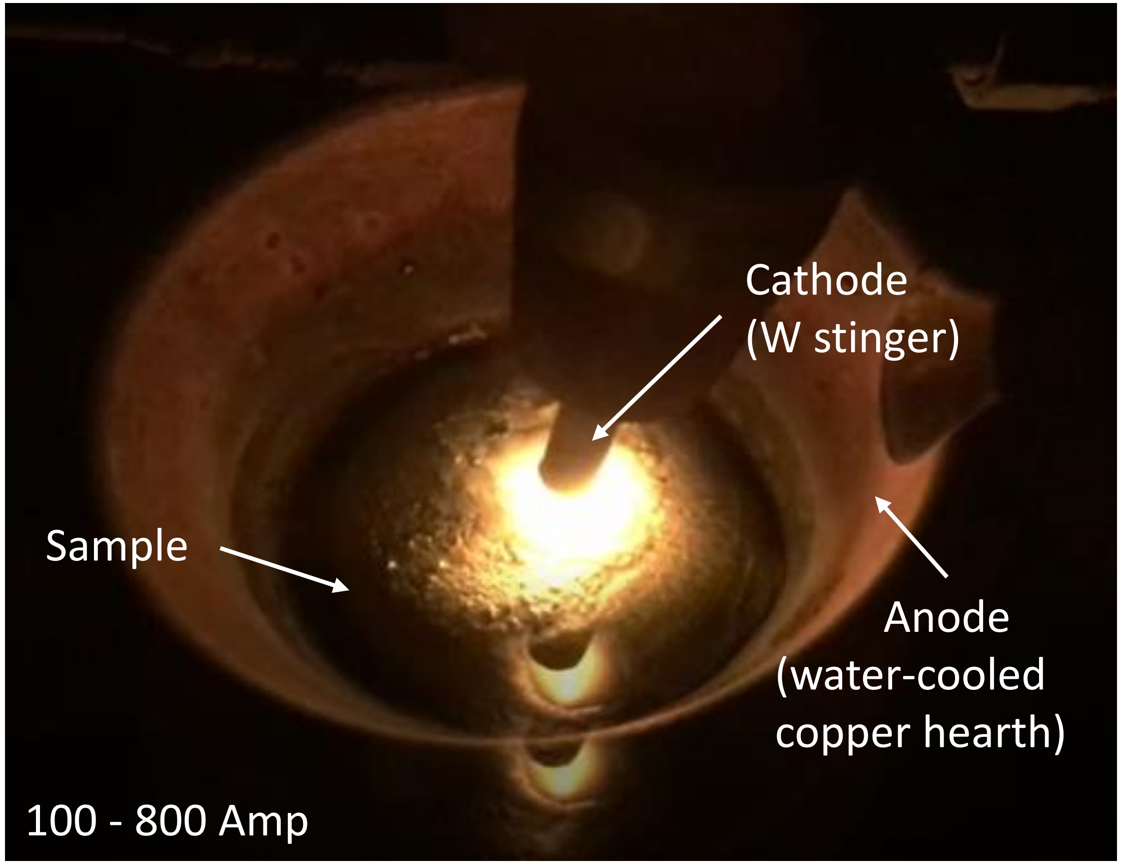
Agenda

- Arc melting overview
  - What's arc melting
  - Rutgers units
- Arc melter as a new research tool:
  - Part I: High temperature ceramics
    - Synthesis of compounds
    - UTHC composites
    - Eutectic composites
  - Part II: Doping and powder synthesis
    - Si-doping
    - Al-doping
    - Challenges

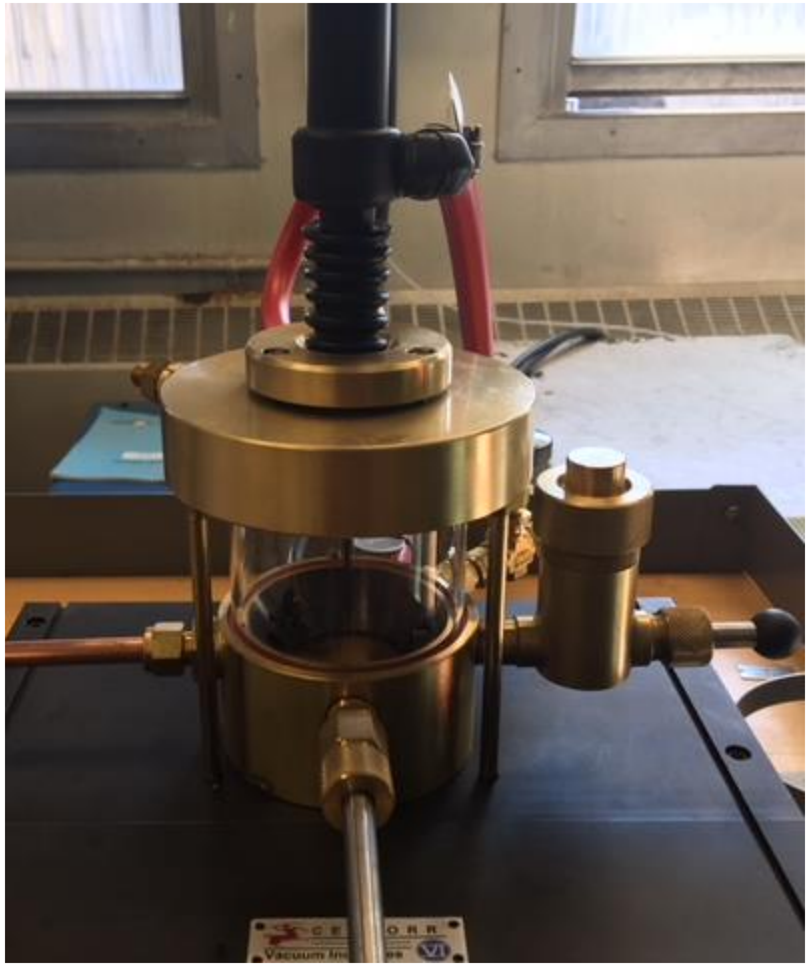
Rutgers arc melter

What is arc melting?

- Electric arc: A continuous high-density electrical discharge through an ionized medium (air or Ar etc.) caused by a dielectric breakdown.
- Temperature: 3,000-20,000 °C (arc flash)
- Operating temperature: >3,500 °C but depends on current density



Our lab-scale arc melters

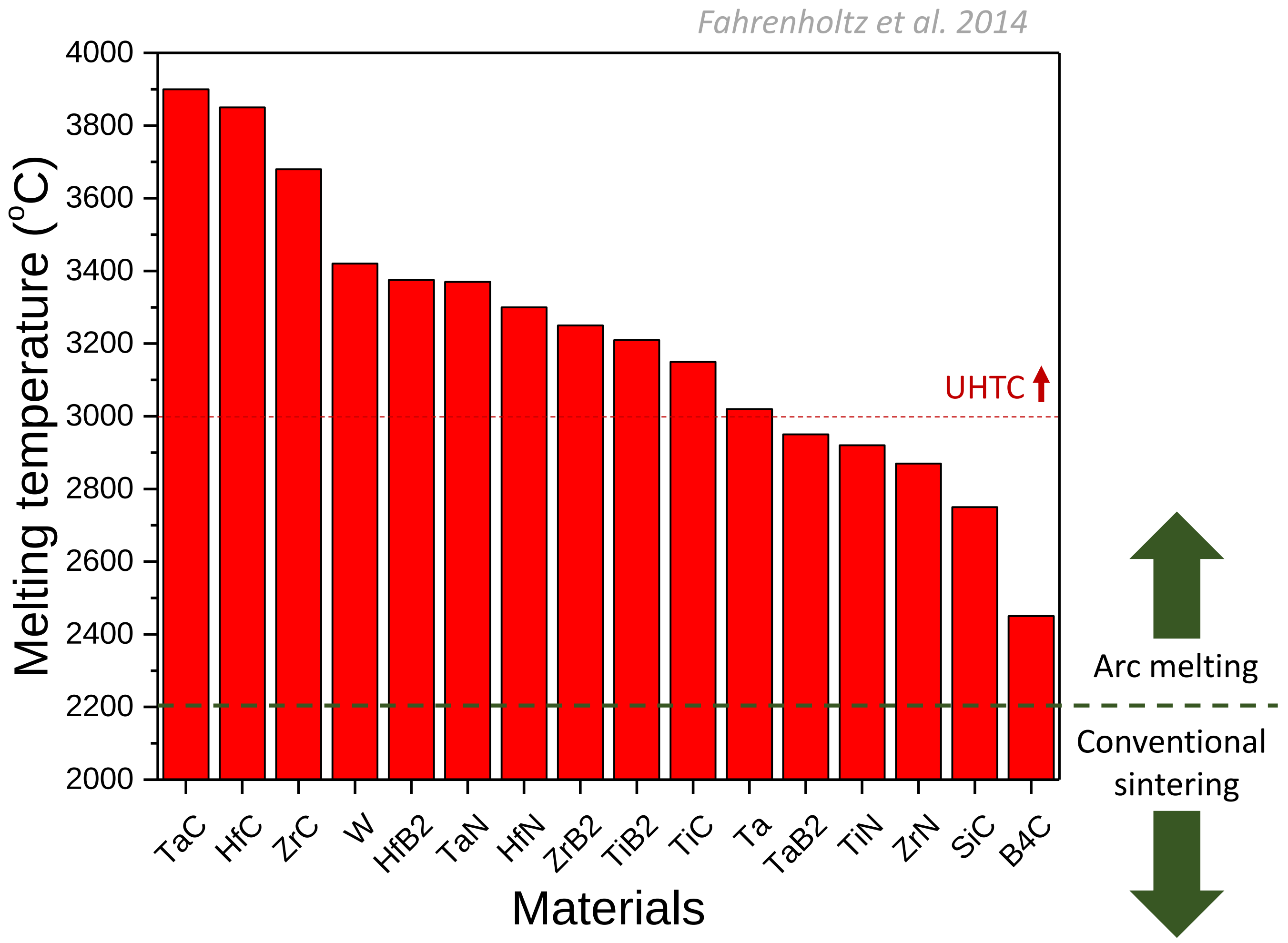


Centorr arc melter
Current: < 350 Amp
W tip: 1.5mm Ø
Capacity: < 1g ceramics
< 10g metals

Arcast arc melter
Current: < 800 Amp
W tip: 9.5 mm Ø
Capacity: < 30 g ceramics
< 100g metals
Attachments: casting molds
vacuum suction
E/M stirring

Part I: Arc melting for high-temperature ceramics

Advantages of arc melting



Advantages:

- Very high processing temperature
- Fast! L → S, no sintering
- Can use powder or chucks
- No powder mixing
- Easy mixing in liquid phase
- Casting/molding complex shapes

Limitations:

- Batch size (industrial-scale do exist)
- Cavities from L → S
- Materials should be “stable” under arc
- Can’t control temperature

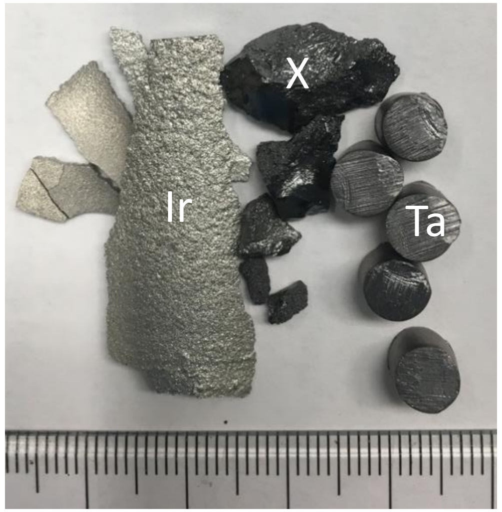
✓Generally applicable for metals and ceramics with high melting temperature

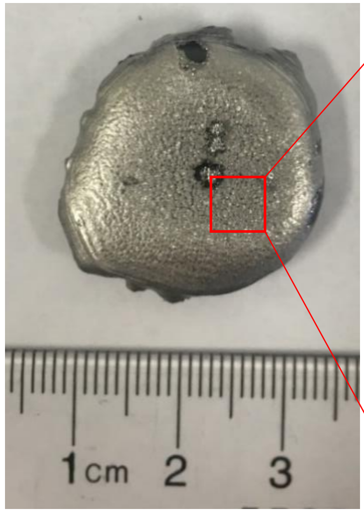
RUTGERS UNIVERSITY

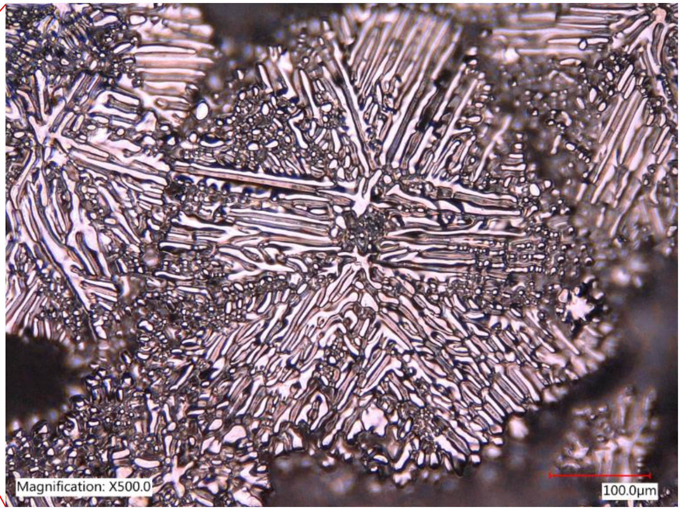
CCOMC Clemson Rutgers Ceramic, Composite and Optical Materials Center

Synthesis of compounds from elements

Raw materials | After melting







<u>Tmelt</u>

Ta: ~3020 °C

Ir: ~2460 °C

Hf: ~2230 °C

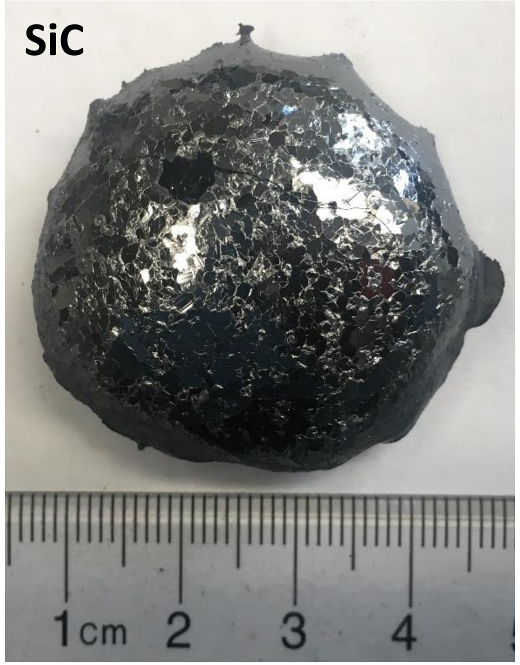
X: ~2000 °C

Y: ~1500 °C

Arc melting provides a <u>fast</u> avenue to process compounds from elements with <u>high melting point</u>

Could be used for high entropy alloys such as (Hf, Ti, Zr, V, Nb, Ta) diborides and other nitride/carbide systems

UHTC composites



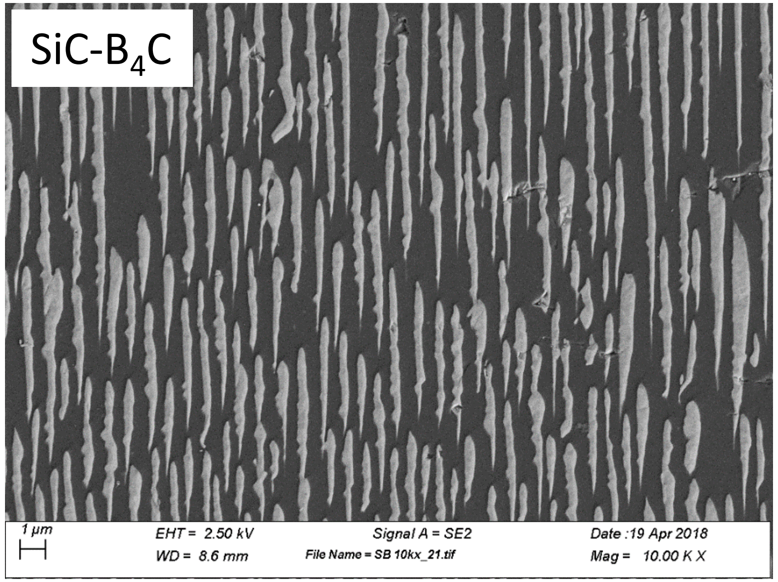
UHTC application:

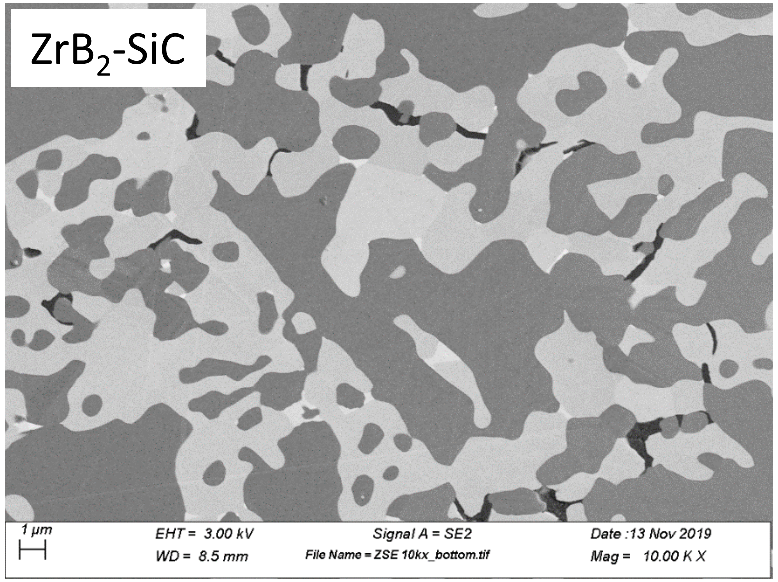
UHTC composites designs

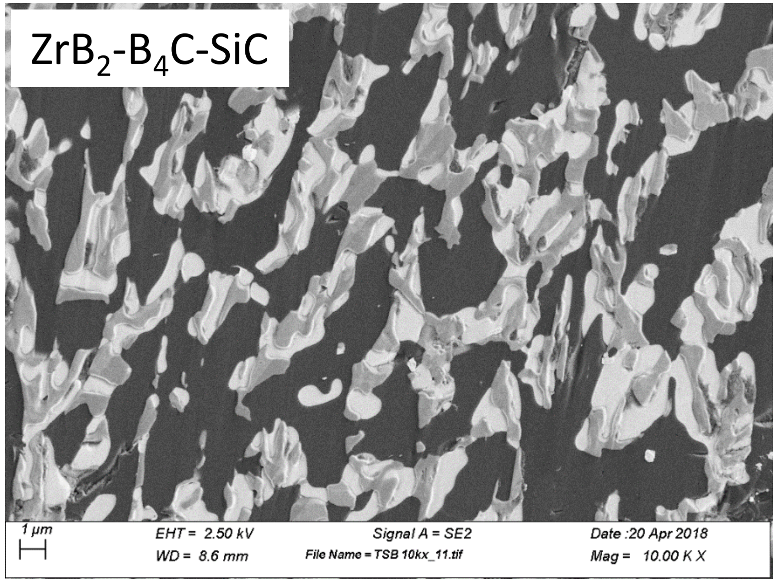
- + SiC → improve oxidation resistance
- + SiC → increase flexural strength
- + B_4C→ increase hardness
- + HfB_2 → increase toughness
- + ZrC → improve thermal conductivity
- other UHTC → fine tune properties

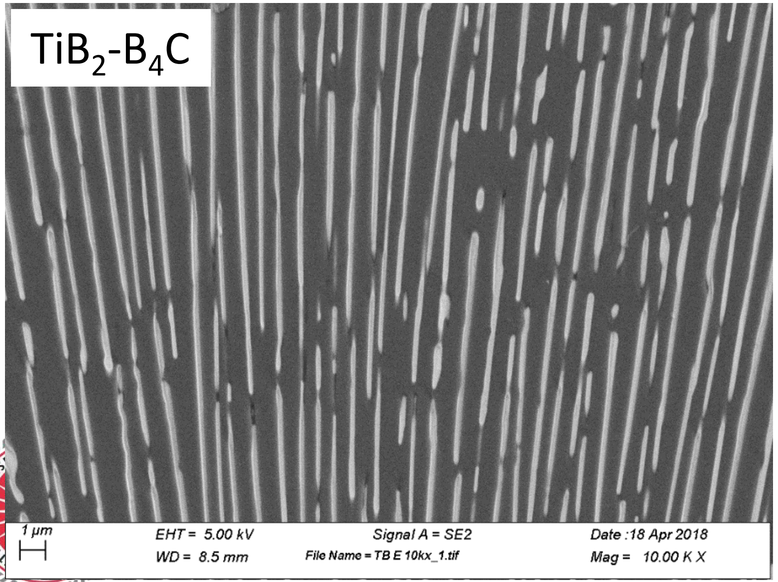
✓ **Fast processing time for cheap!**

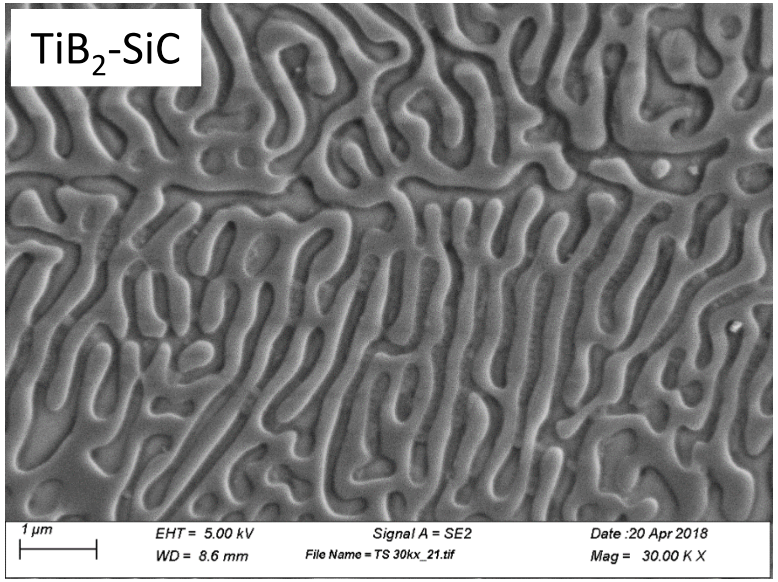
Ceramic eutectic systems

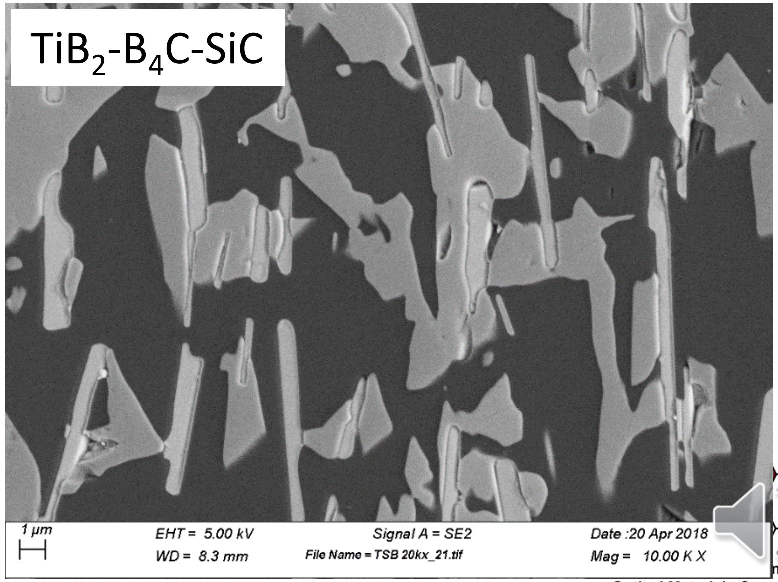








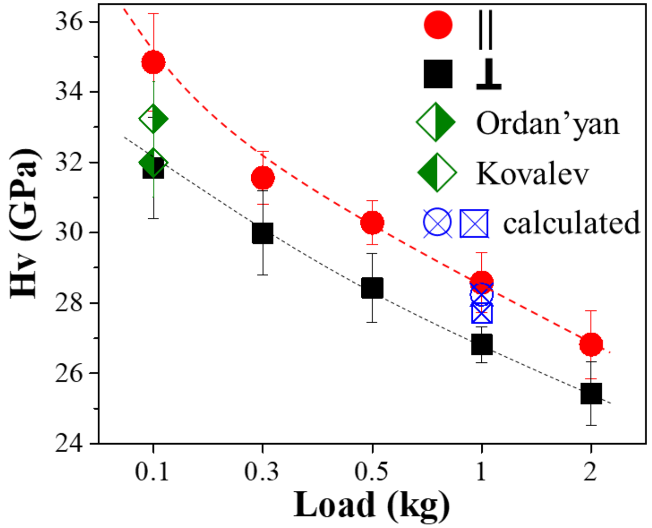


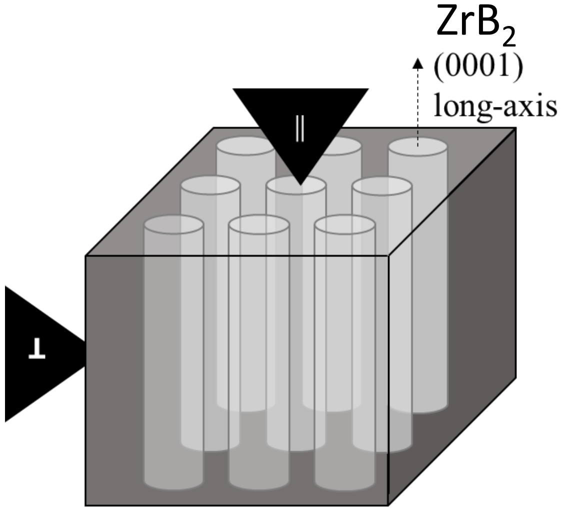


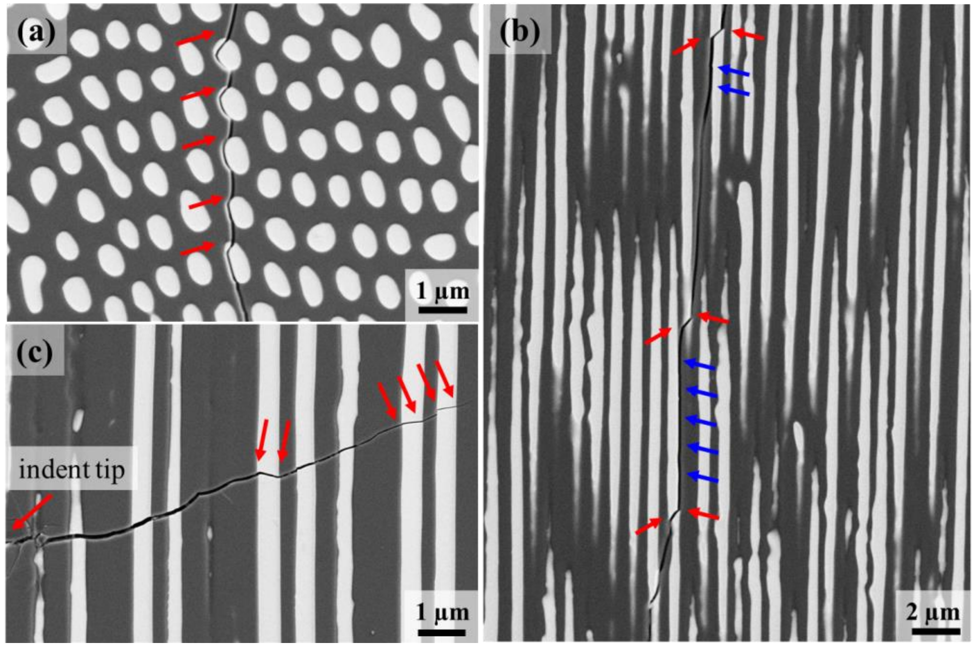
ZrB_2—B_4C eutectic system

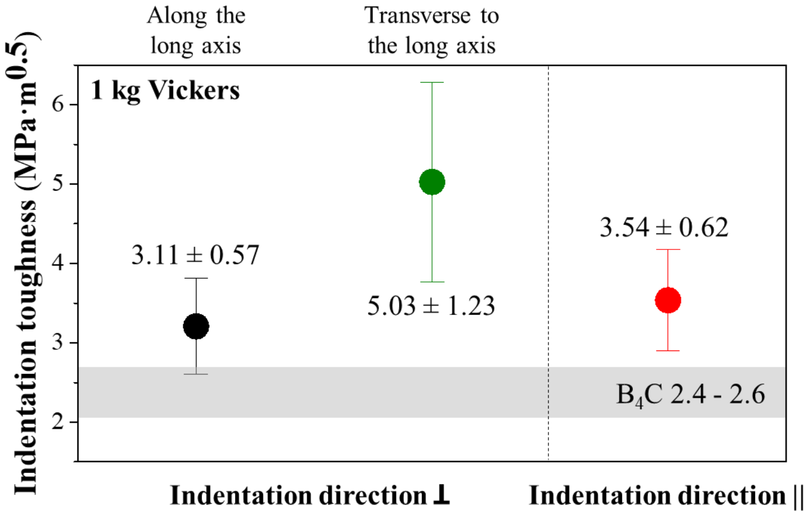
Why eutectic?

1. Fine microstructure → excellent mechanical properties
2. Secondary phases → improves toughness; alter fracture behavior
3. Microstructure texturing → anisotropy







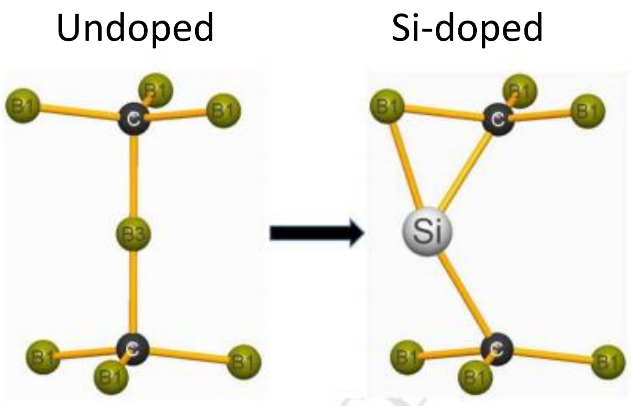


- Hardness and toughness anisotropy due to microstructure texturing
- Electronic and physical properties could also experience anisotropy

Yang et al, Mater. Chara. (2019) 155, pp. 109797

Part II: Arc melting for doping and powder synthesis

Si-doping in boron carbide



Q: Why Si-doping?

A: Si-doping emerges as the primary strategy to mitigate stress-induced amorphization, a phenomenon believed to cause boron carbide's unexpected glass-like fracture behavior under high stress impacts.

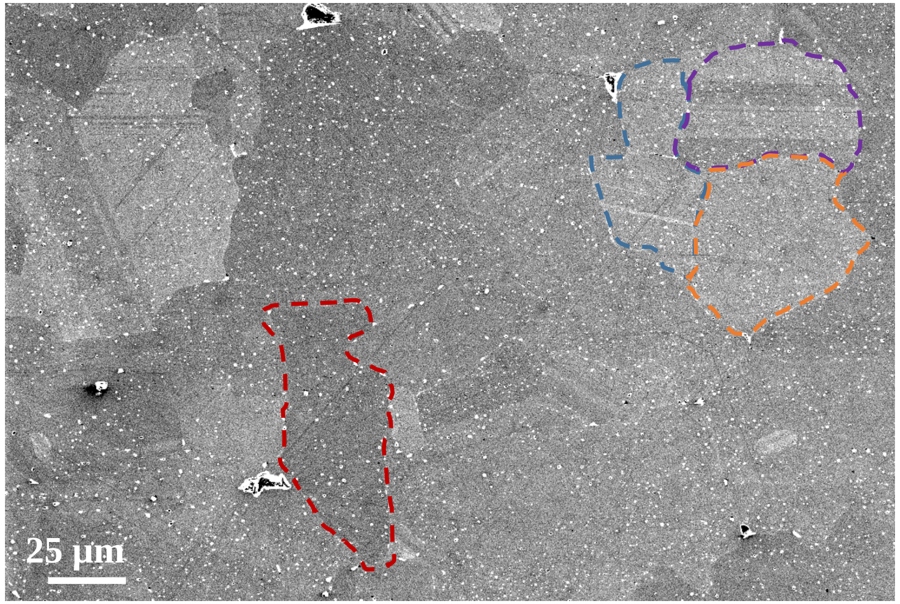
Existing methods for Si-doping

Method	Processing time (hr)	Specimen scale	Microstructure control
High energy ball milling	10+	µm	NA
Nano-rod growth	10+	nano	NA
Diffusion couple	4-6	100s µm	No
Reaction hot pressing	4-6	mm-cm	Little to none

In need of a scalable processing method that also allows for microstructure control

Why arc melting for Si-doping

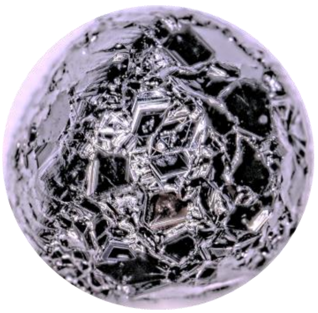
Si-doping through rxn hot pressing



- Rapid grain growth due to liquid phase sintering
- Decreased in mechanical properties

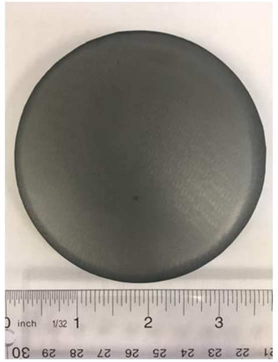
Three-step approach

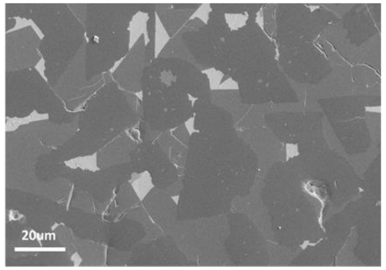
Arc melting



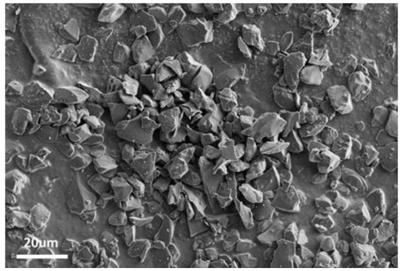
Particle size refining

Hot pressing

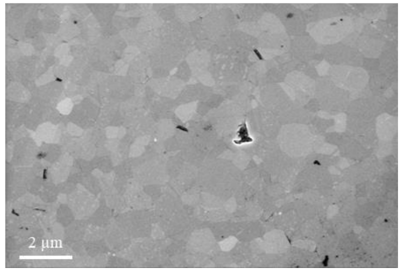




Pre-reacted feedstock



Pre-reacted powders

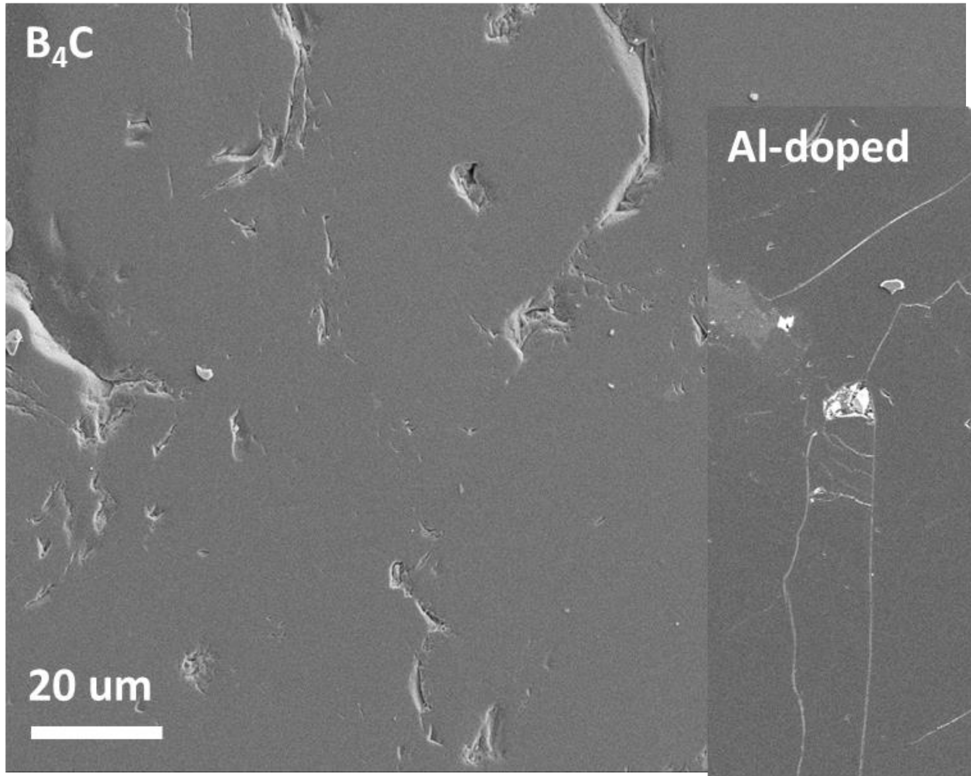


Final microstructure

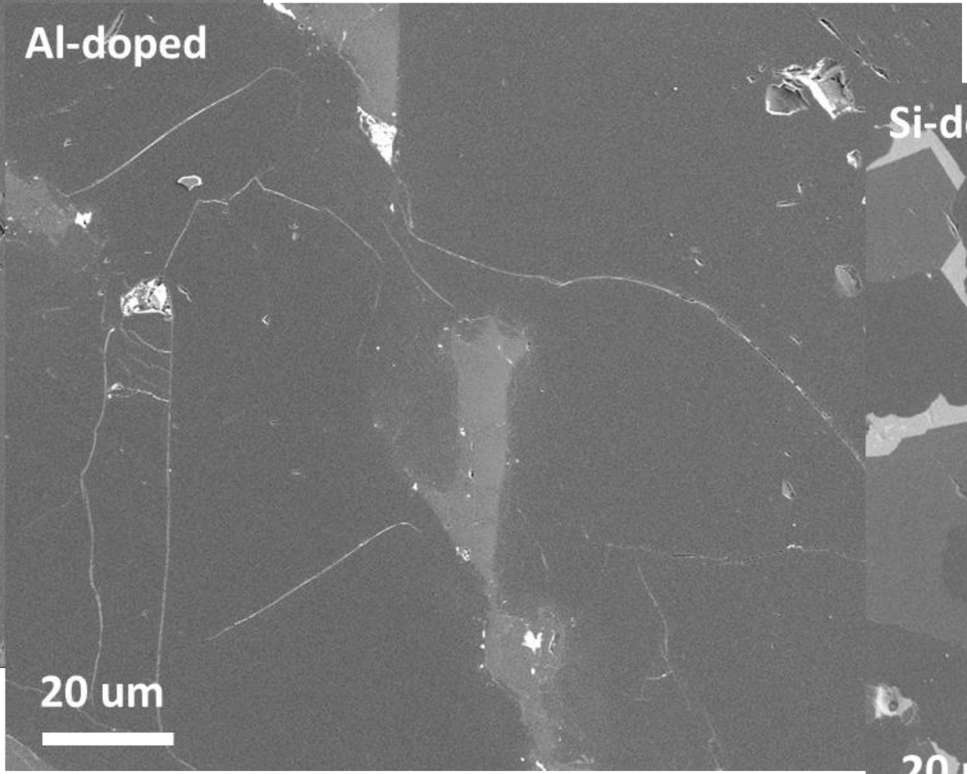
- Can control the melt composition → powder with a variety of chemistry
- Powder is already pre-reacted → less time than reaction hot pressing → smaller gains
- Control powders size → control microstructure
- The three-step approach mimics the existing industrial process for producing boron carbide powder

Microstructure after melting

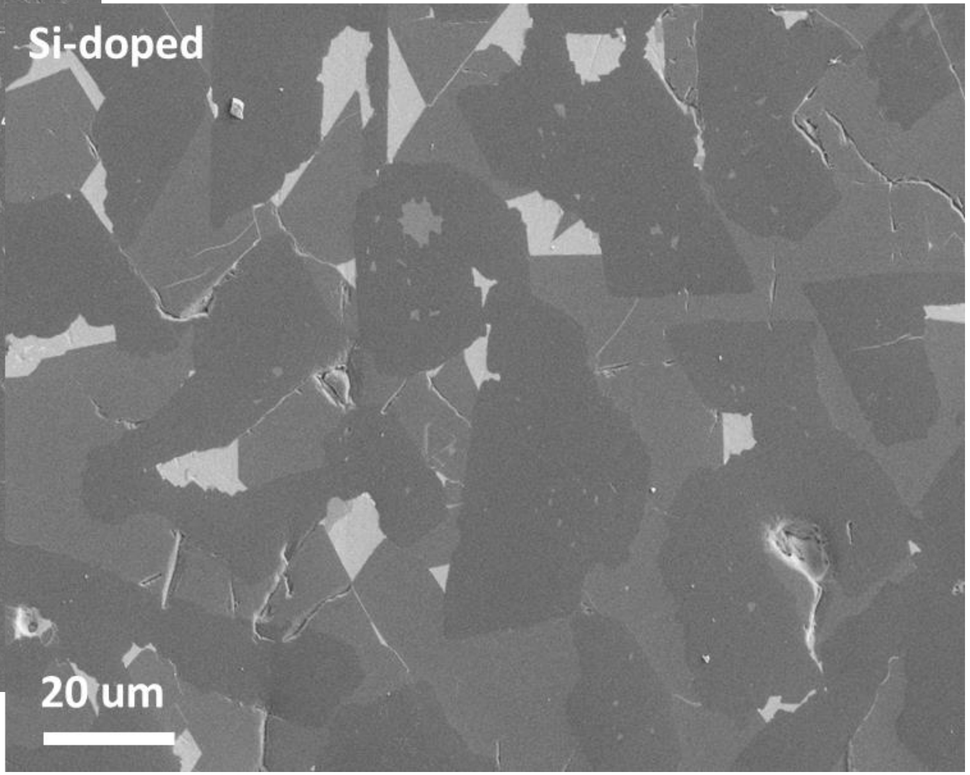
- Multiphase materials
- Dense microstructures



Monolithic boron carbide



Al, $B_{38}Al_3C_2$, undoped and Al-doped boron carbide

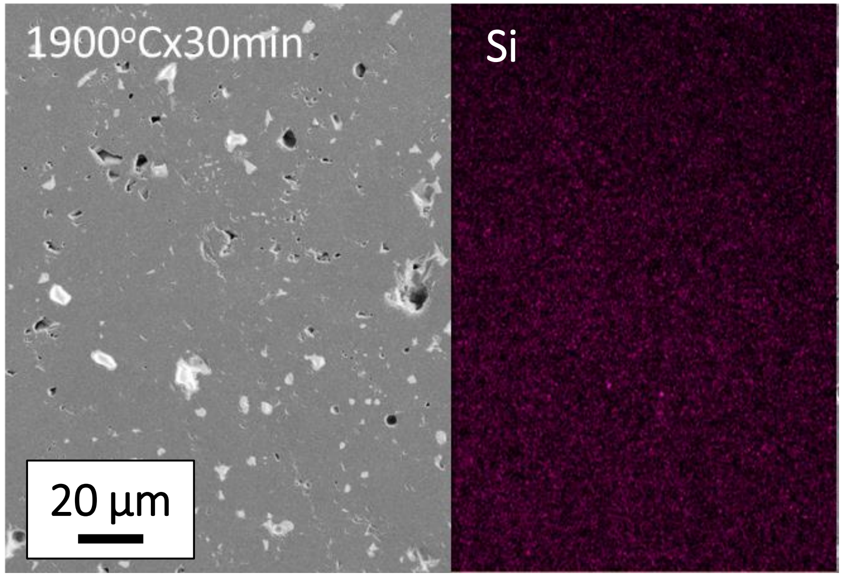


SiB_6, Si, undoped, and Si-doped boron carbide

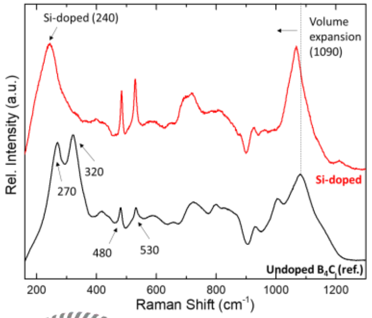
Yang et al, J. Eur. Ceram. Soc. (2019) 39, pp. 5156-5166

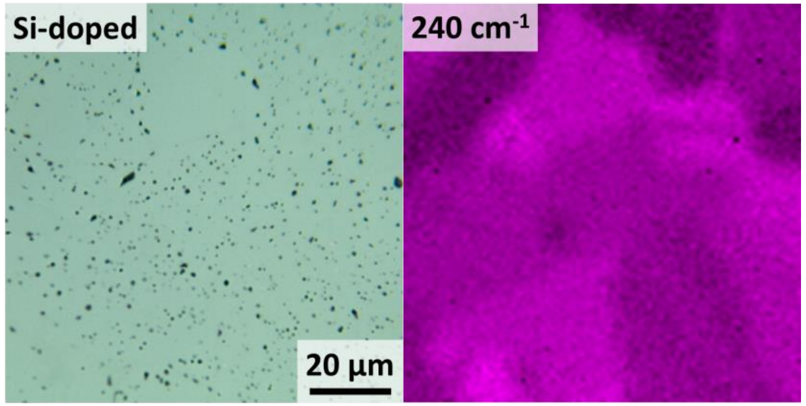
Doped powders sintered

Si-doping boron carbide

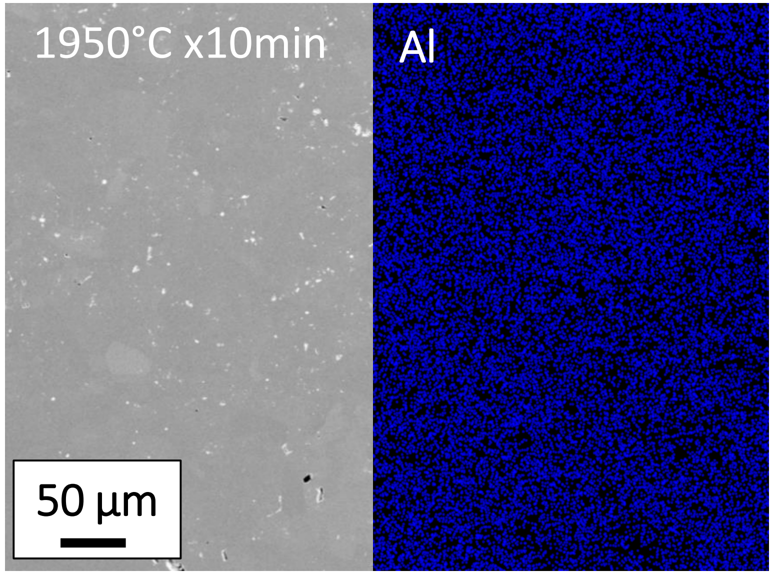


Raman mapping

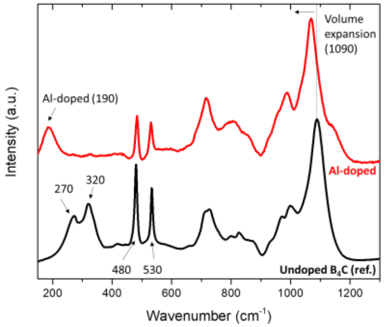


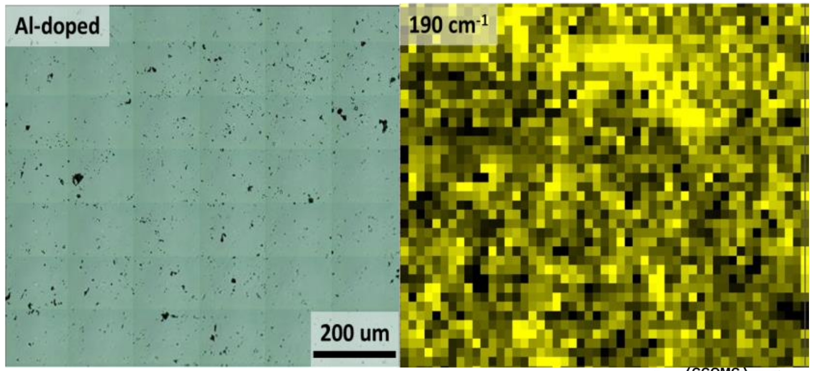


Al-doping boron carbide



Raman mapping



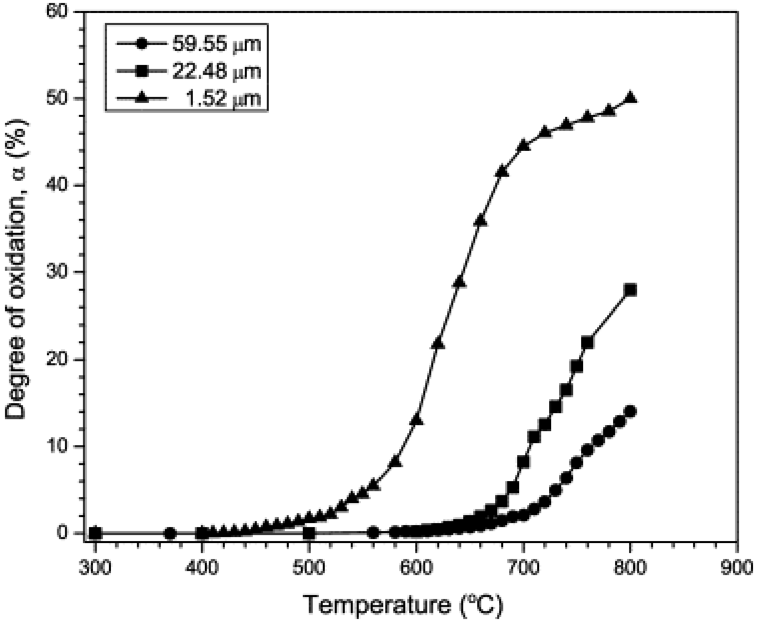


RUTGERS UNIVERSITY

- Si- and Al-doped boron carbide bulk samples processed using the three-step approach

CCOMC Clemson Rutgers
Ceramic, Composite and Optical Materials Center

Challenges in particle refinement



- Difficult to obtain 100s µm feed
- Minimize contamination from the particle refinement process → avoid using foreign grinding media
- Prevent oxidation on the milled powders → mill in solvent and dry in vacuum ovens

Melted feedstock
3-4 cm

→

Jaw crusher
(Steel)
1-3 mm

→

Mortar and pestle
(steel)
<1 mm

Jet mill
(WC)
100s µm

→

Netzsch
(polymer)
<10 µm

Attritor
(SiC)
<10 µm

RUTGERS
UNIVERSITY

Optical Materials Center

Key takeaways

Part I: Arc melting of high temperature ceramics

Versatile research equipment for

- Synthesis of compounds from high melting temperature elements (Ta, Ir, Hf)
- UHTC composites
- Eutectic composites

Part II: Doping and powder synthesis

- Si- and Al-doped powders synthesized
- Si- and Al-doped boron carbide bulk materials were fabricated
- Refining the particle reduction method to minimize oxidation and contamination

Acknowledgements

Thank you for your attention
Questions?

Qirong “Bruce” Yang
qy48@scarletmail.rutgers.edu