Metal Silicide Reaction-Bonded SiC for Fusion

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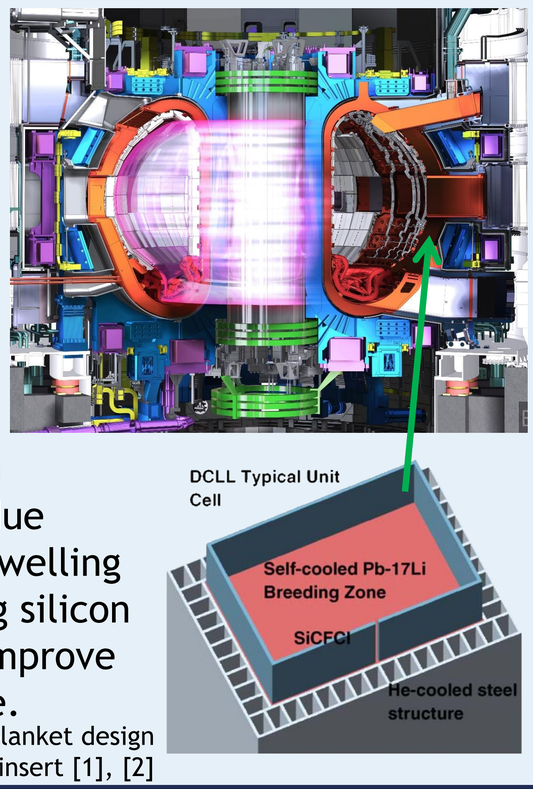
Fusion applications

Silicon carbide is intended for use in the breeding blanket of future fusion reactors due to its corrosion resistance, high temperature strength, low thermal expansion, good thermal conductivity, and low nuclear activation.

RB-SiC is simple to make in the required shapes, but radiation resistance needs to be improved due to differential radiation-induced swelling between silicon and SiC. Replacing silicon with a metal silicide is hoped to improve toughness and radiation resistance.

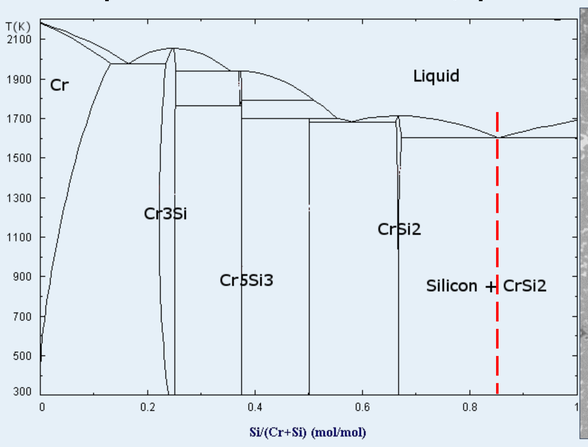


Iter fusion reactor (top) with a blanket design concept using SiC as a flow channel insert [1], [2]

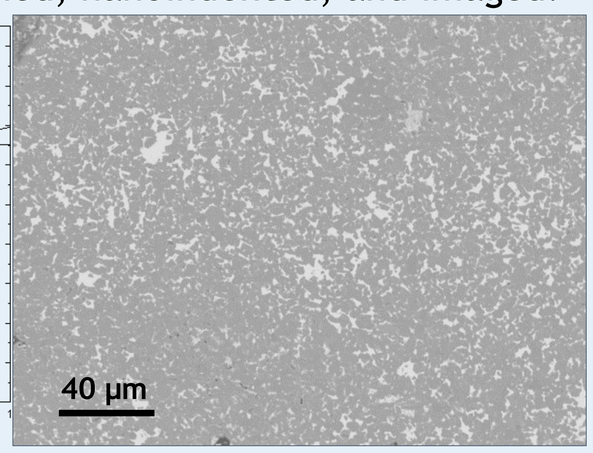
Processing with Si-alloys

Silicon alloys were made by arc melting silicon with chromium, or tungsten, at near-eutectic compositions.

These were melt infiltrated into SiC/carbon black porous preforms in vacuum. **Si + C → SiC + residual *disilicide*.** Samples were sectioned, polished, nanoindented, and imaged.

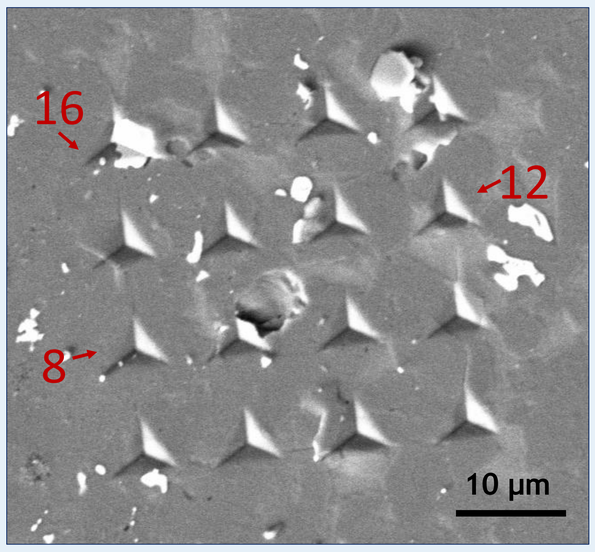


Chromium – silicon phase diagram showing eutectic composition of silicon and silicide. [3]



RB-SiC with Si-Cr alloy 1500ºC, 30 minutes. 15.8% $CrSi_2$ 84.2% SiC

SiC/WSi_2/Si

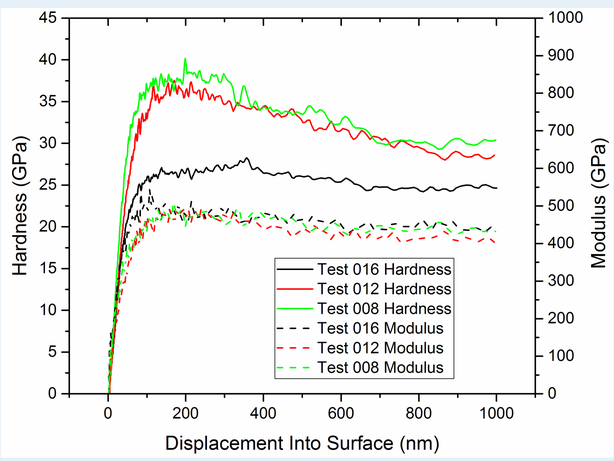


Si-4.4at% W, infiltration at 1700˚C, 10 minutes.

Full infiltration into 4 mm bodies

3.5% WSi_2, 9% Si, 87% SiC, 0.5% porosity by image analysis

1000 nm Berkovich indents



Relatively little corner cracking compared to monolithic SiC

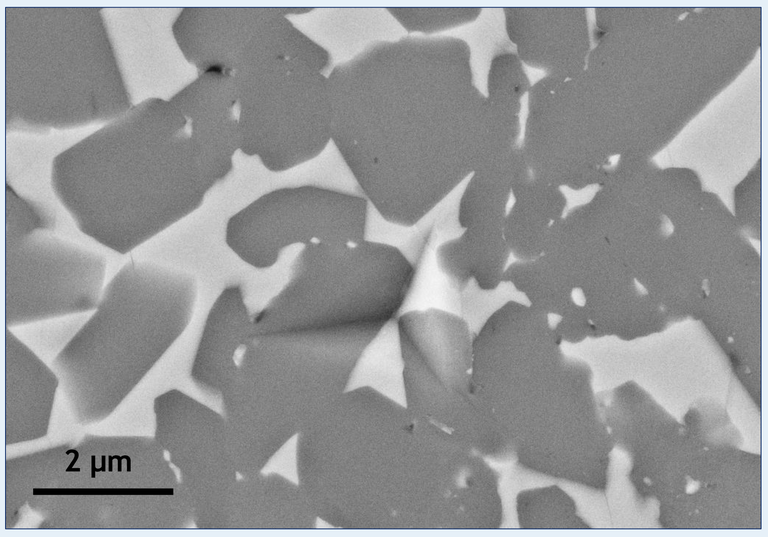
Hardness and modulus of selected indents showing properties of SiC and a SiC/WSi_2 indent. Reduction in hardness due to nearby silicon regions

SiC/$CrSi_2$

Si-13.2at% Cr, infiltration at 1500˚C, 30 minutes

~1.5 mm partial infiltration into 4mm thick green bodies.

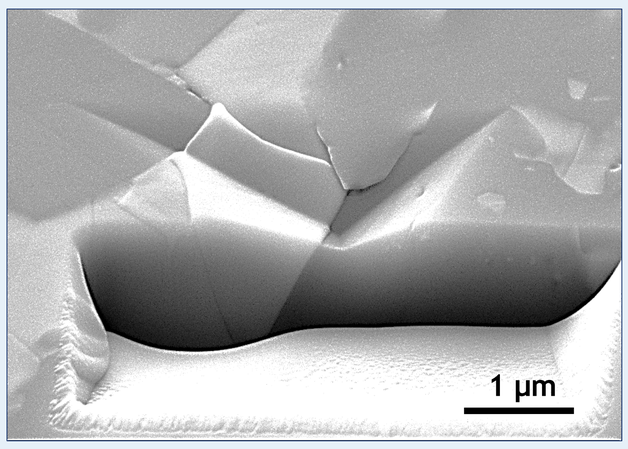
15.8% $CrSi_2$, 84.2% SiC by image analysis



500 nm Berkovich indent

Less cracking and different crack morphology compared to conventional SiC

No visible sub-surface cracking in this FIB milled cross-section



Conclusions and future work

- ✓ Silicon can be replaced in RB-SiC with a metal silicide via eutectic alloy reactive melt infiltration
- ✓ Nanoindentation shows reduced cracking
- ✓ Raman stress mapping of residual phases and indents
- ✓ High energy ion implantation to simulate radiation damage

- ○ *EBSD strain mapping*
- ○ *Corrosion in molten Li-Pb alloy for breeder blanket compatibility*

References & Acknowledgements

[1] Credit © ITER Organization, http://www.iter.org/
[2] Ying, A. et al., 2006. An overview of US ITER test blanket module program. *Fusion Engineering and Design*, 81 A(1–4), pp.433–441
[3] Davies, R.H. et al., 2002. MTDATA-thermodynamic and phase equilibrium software from the national physical laboratory. *Calphad*, 26, pp.229–71

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Recent work: nanoindentation plasticity, and observation of reaction-formed SiC

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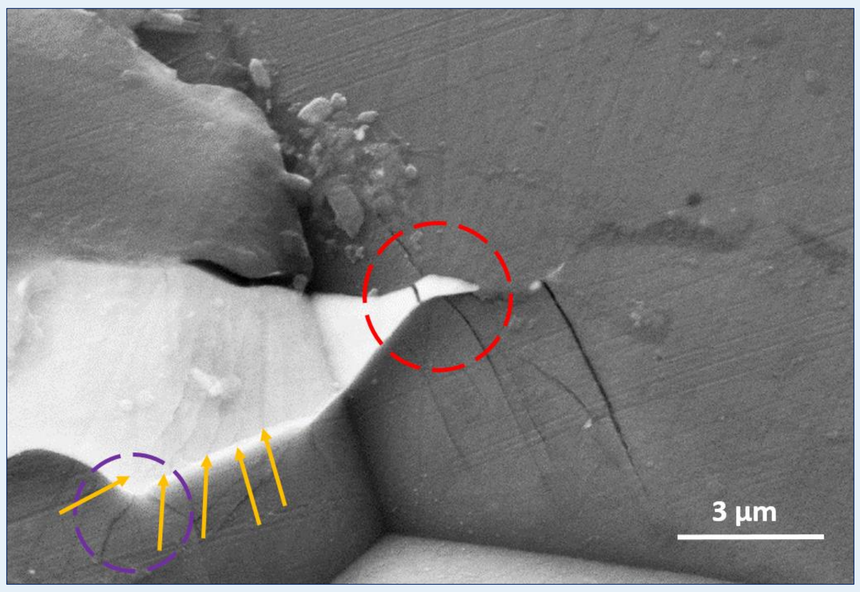
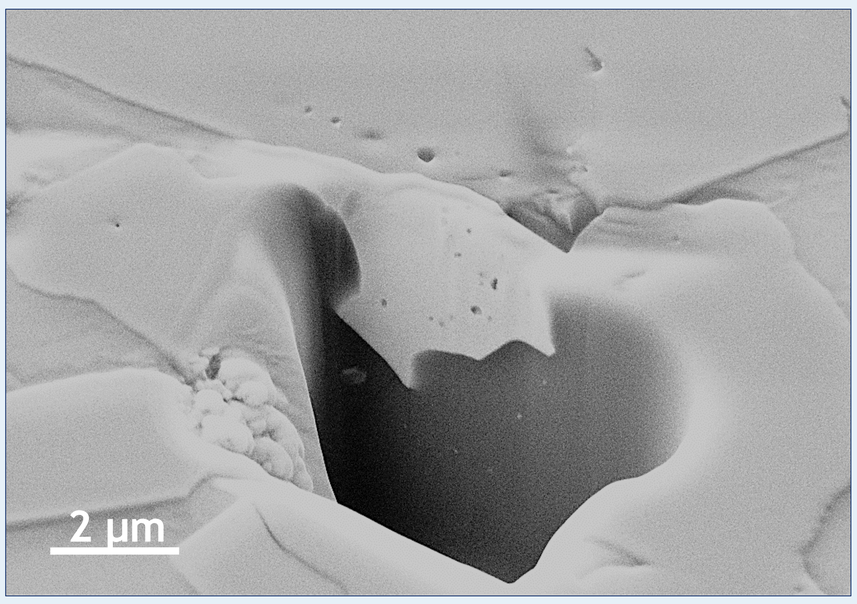
SiC/WSi_2/Si nanoindent

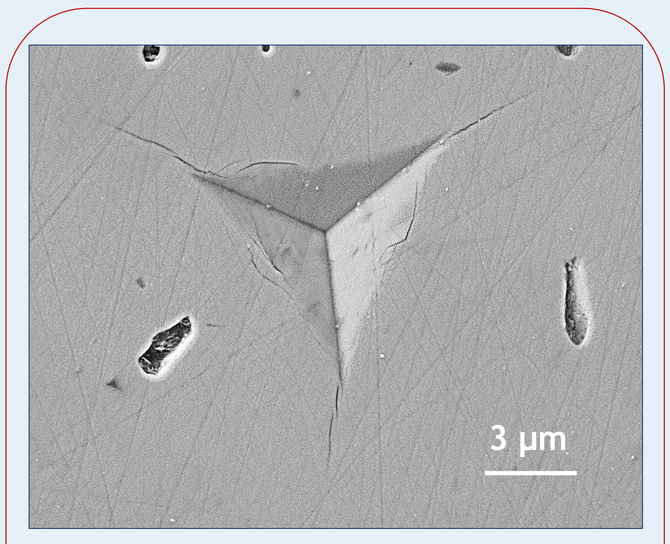


1000 nm Berkovich indent and FIB cross-section

Purple circle shows a crack stopping when it reaches WSi_2
Orange arrows show plasticity (or cracking)
Red circle shows WSi_2 pulling out or crack bridging the SiC matrix

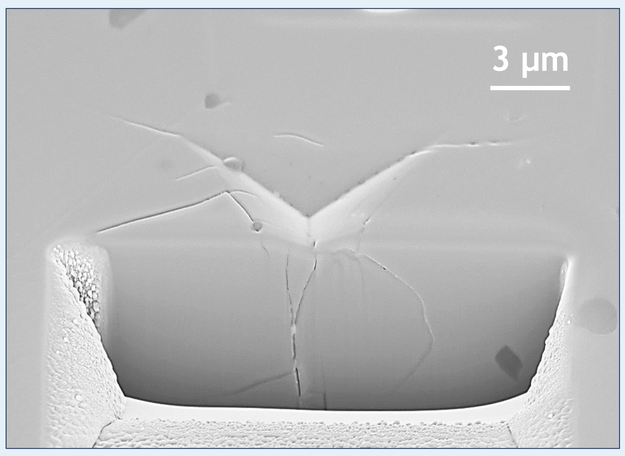
No visible sub-surface cracking





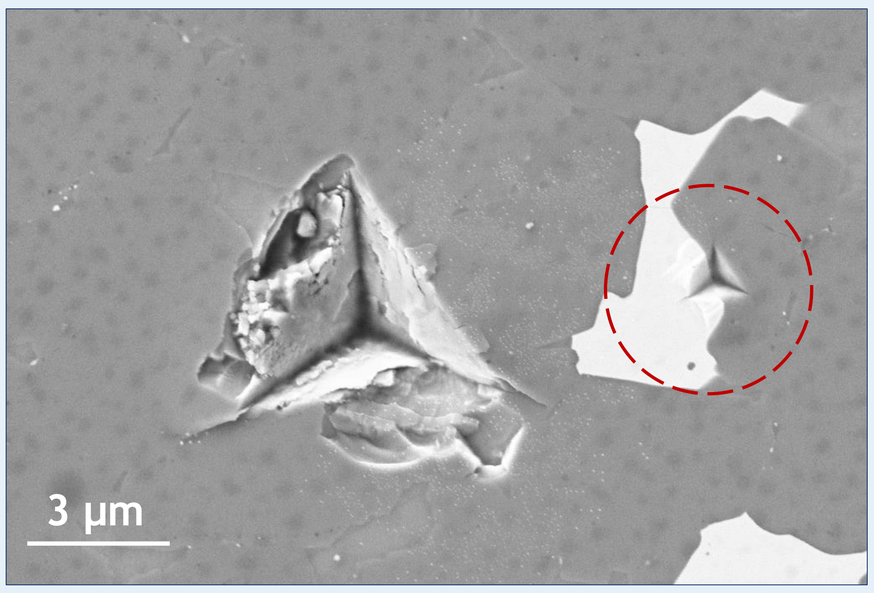
Sintered SiC indent: corner and lateral cracking

FIB cross-section showing sub-surface cracking

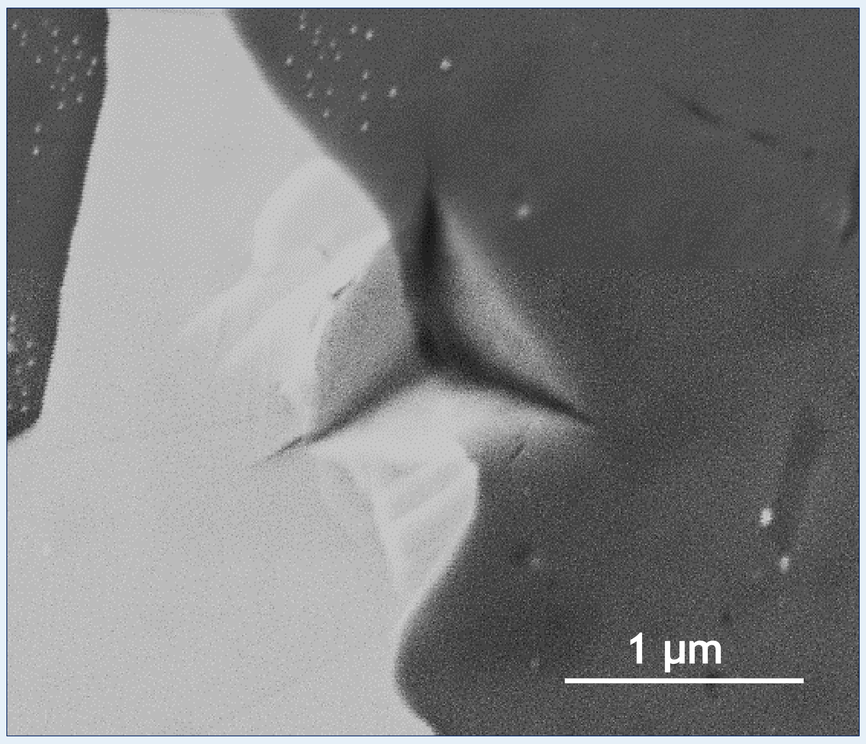


(Sintered SiC images by Helen Pratt)

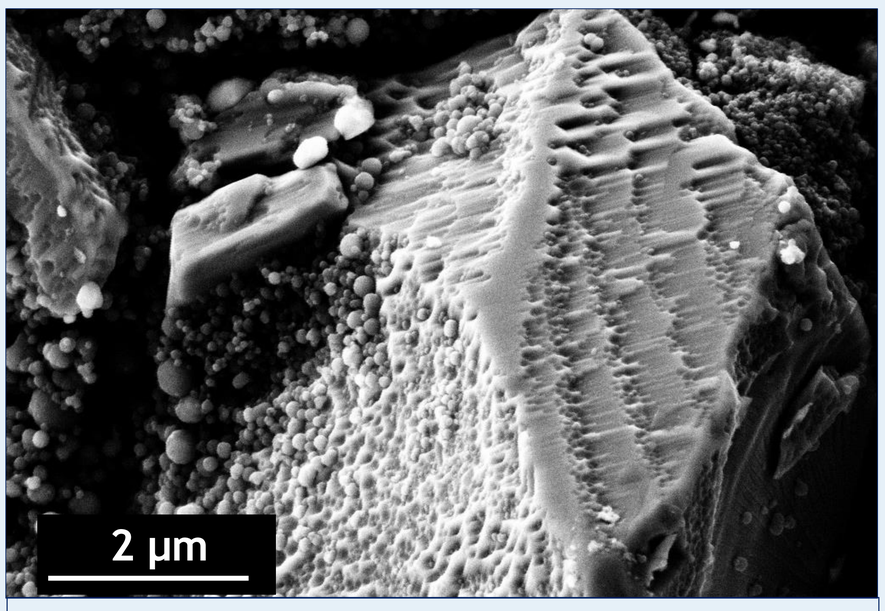
Ion irradiated SiC/WSi_2/Si indents



2000 nm cube-corner indent into SiC/Si region and a 500 nm cube-corner indent into SiC/WSi_2 region (red circle expanded below)
Some signs of plasticity in the WSi_2 phase along the indenter edges



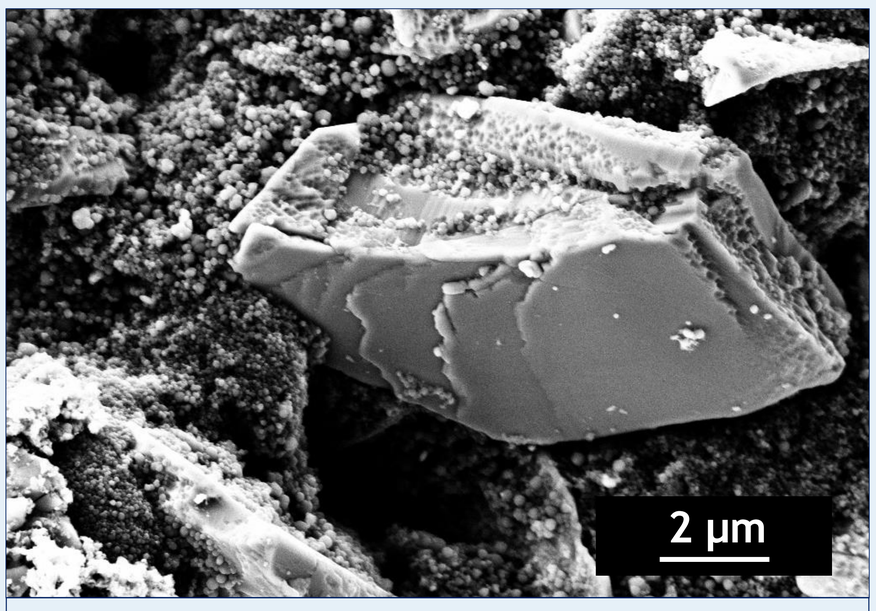
Formation of RB-SiC



Growth fronts of SiC growing on a 6H-SiC grain

The mechanism of reaction formed SiC is disputed: nucleation and growth from carbon-saturated solution, or by diffusion controlled transformation of a carbon layer.

These images of grains in partially reacted RB-SiC which was starved of silicon suggest that SiC grows epitaxially on the existing SiC grains rather than by diffusion of carbon or silicon through a SiC layer. *Further investigation required.*



Stepped layers of SiC growing on a 6H-SiC grain

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