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Capacitive Discharge Resistance Welding for ODS Steel Cladding: Weld Properties and Radiation Resistance

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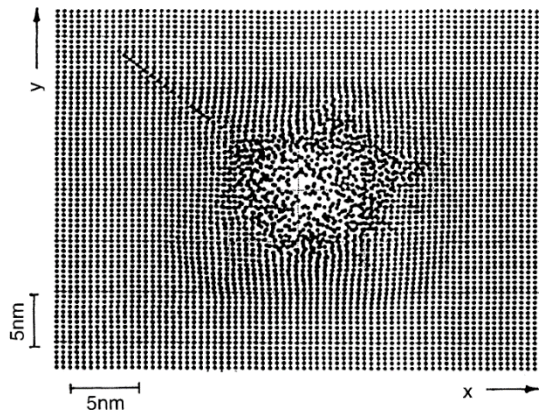
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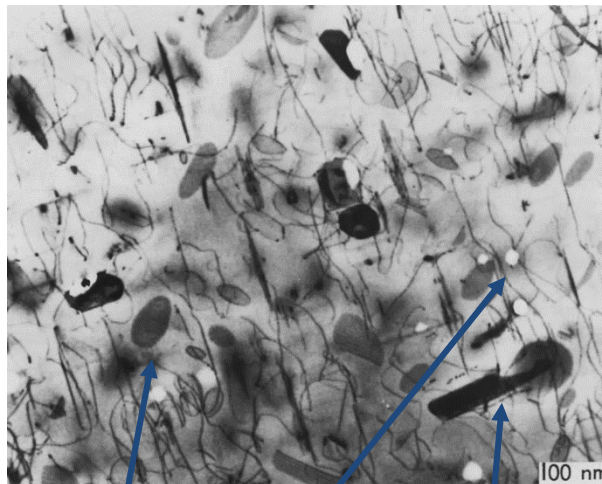
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Radiation damage and induced microstructural change present an on-going materials challenge



Averback & Ghaly

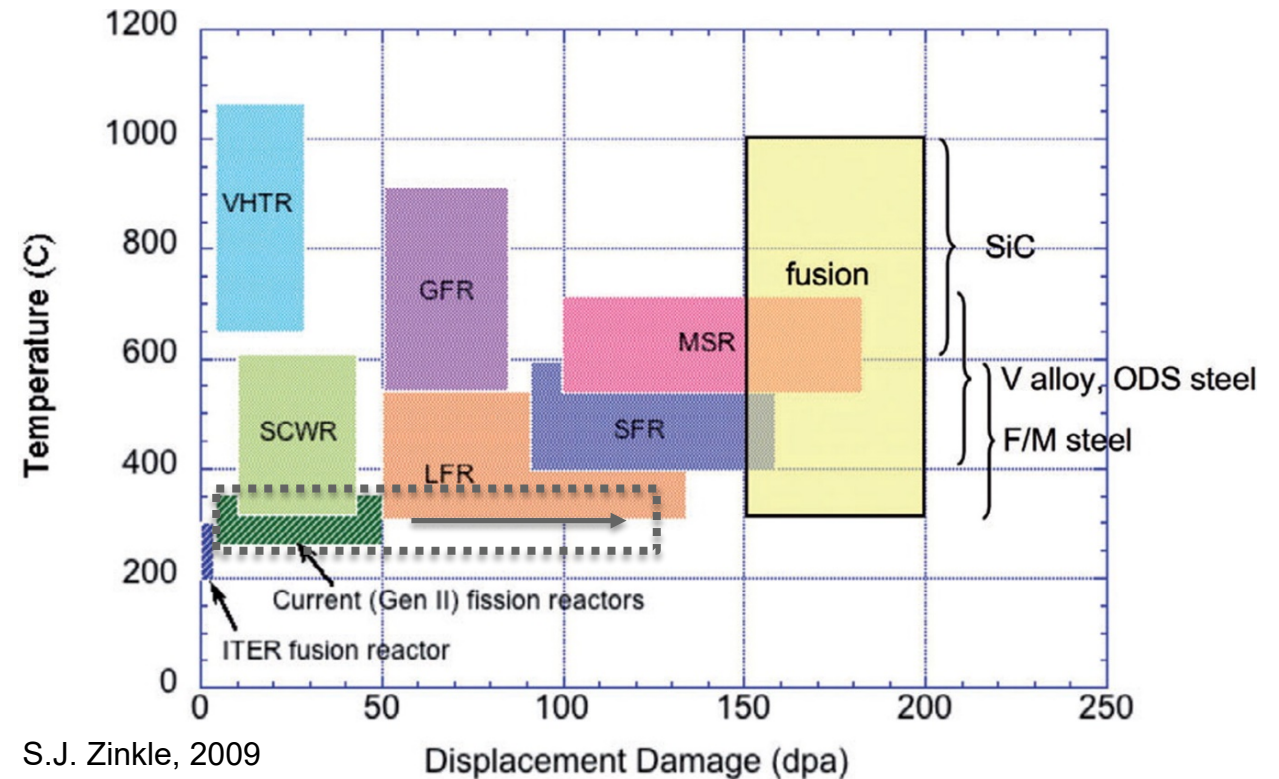


Dislocation
Loops

Cavities

Precipitates

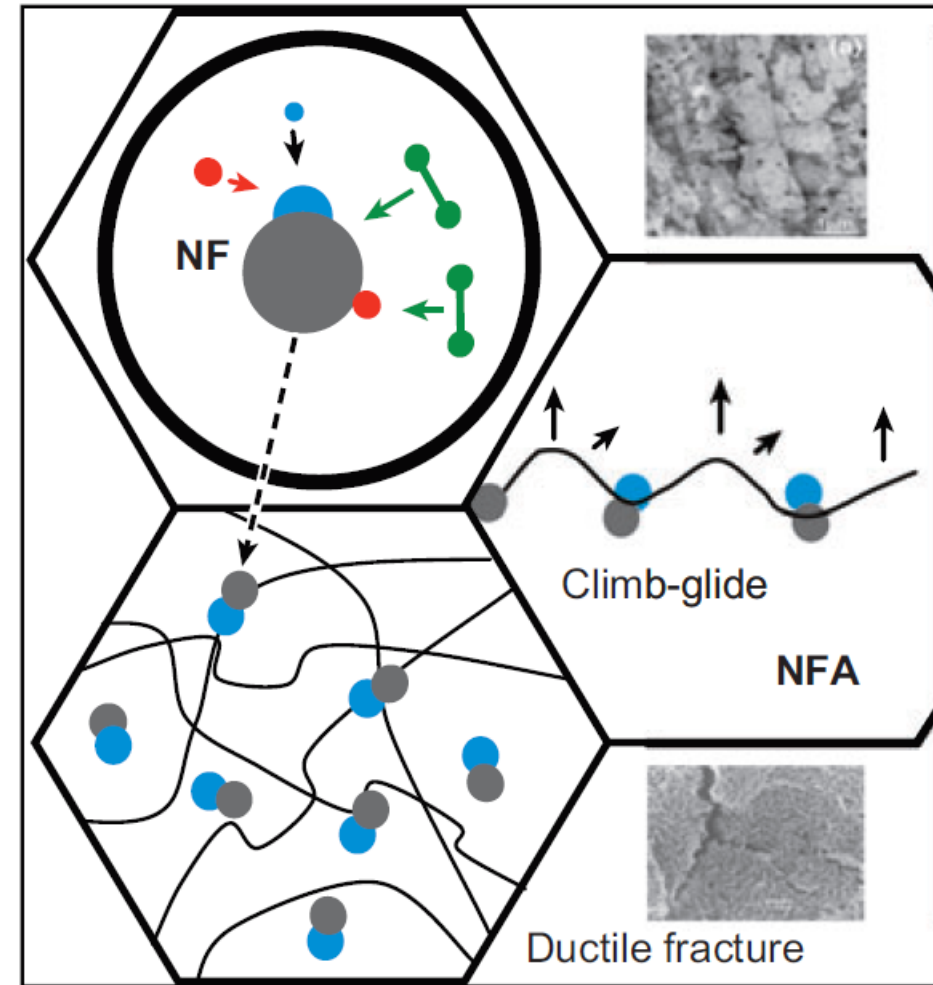
J.O. Stiegler, 1979



- Materials development for high T , high ϕ Gen IV and fusion reactors
- Vetting current materials for Gen II/III reactor life extension (dashed box)

Nanostructured materials trap defects and gasses, limiting evolution and minimizing deterioration

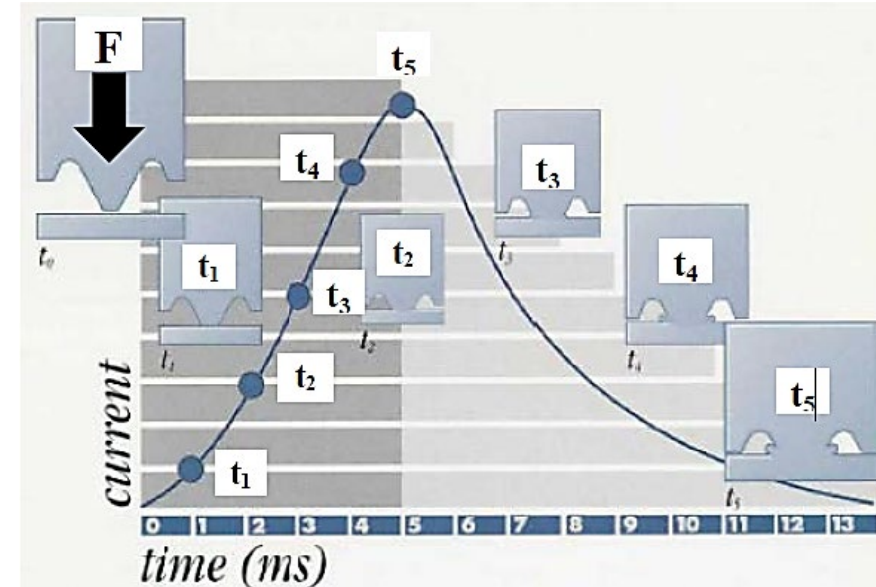
- Nanostructured ferritic alloys (NFA) are formed by mechanical alloying for fine grains and high densities of nanoscale features
 - Resistance to creep and coarsening at high temperature
 - Voids/bubbles kept small and off grain boundaries via abundant nucleation
- Oxide dispersion strengthened (ODS) alloys are promising NFAs, as Y, Al, and Ti based nanoparticles are fully incoherent and very stable with irradiation
- With proper chemistry, NFA ODS materials have also shown improved high temperature oxidation resistance vs. conventional claddings



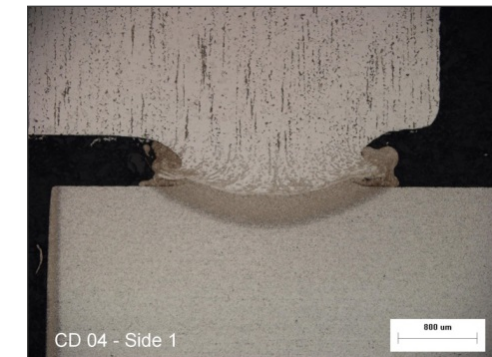
G.R. Odette, 2008

Difficulties joining these advanced alloys, however, require unconventional techniques

- Conventional fusion techniques degrade microstructure via heat input and local melting
 - Growth of nano-scale grains
 - Coarsening, agglomeration, or redistribution of ODS particles in molten regions
- Other solid-state welding techniques impractical for small/thin cladding applications
- Capacitive discharge resistance welding (CDRW)
 - Projection welding focuses current to an intense, short-lived point
 - Collapsing projection forces out surface oxides, provides bonding layer material
 - Capacitive discharge guarantees rapid thermal cycles, no excess heating

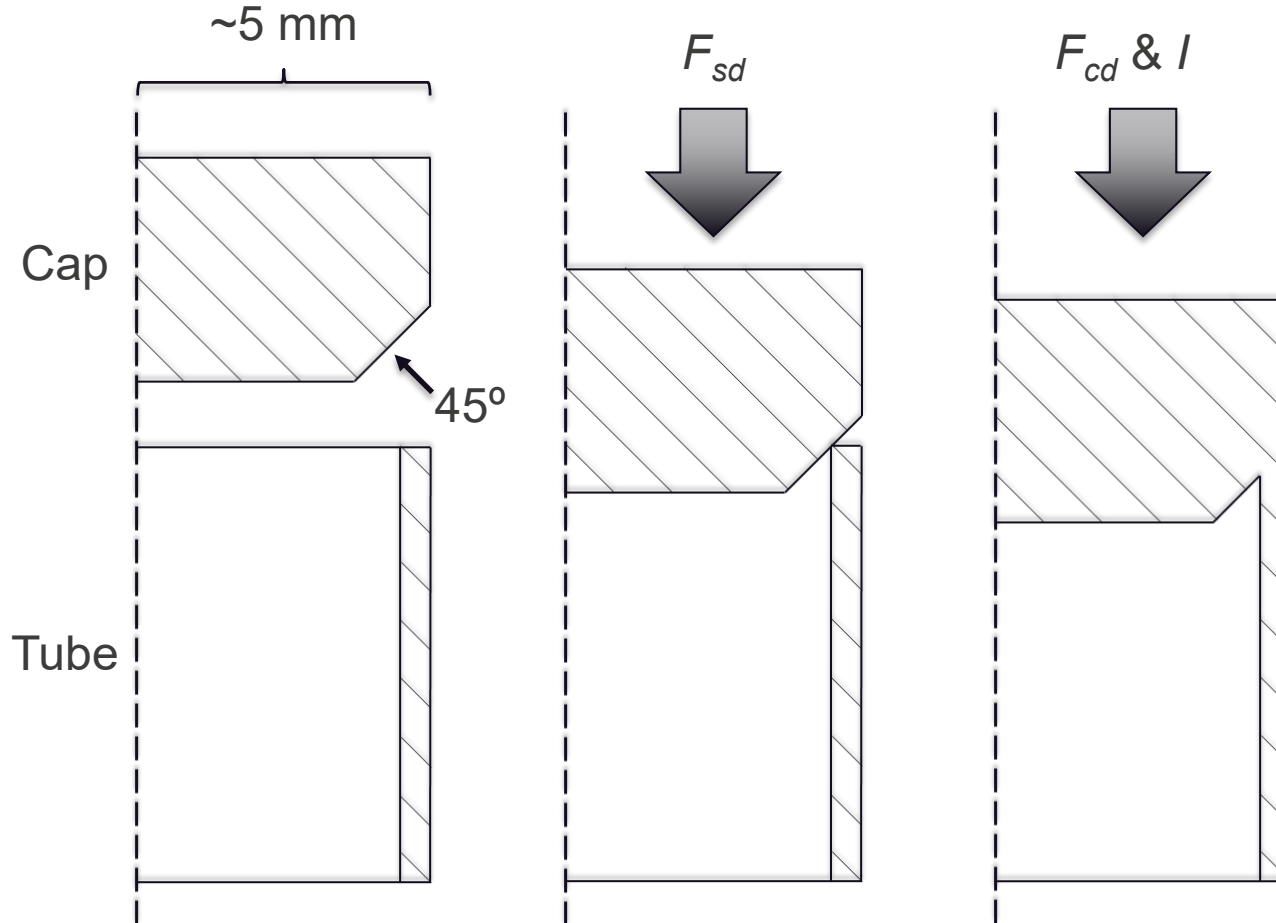


~10-20% the
time-scale
of PRW!



CD Power Smallest HAZ
Improved Deformation of Base Material

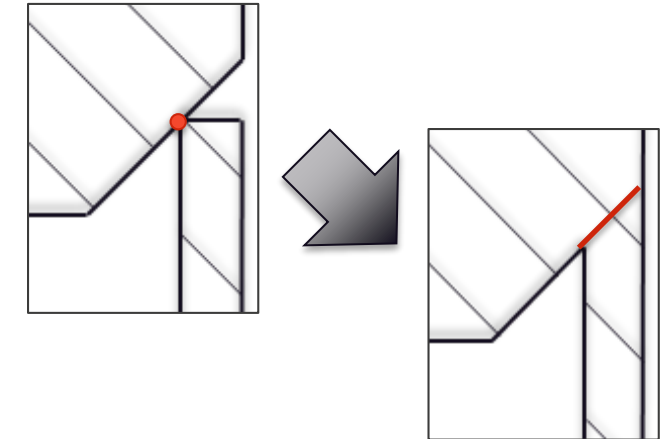
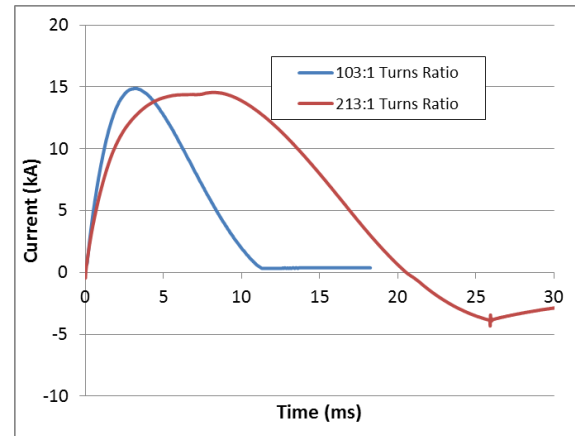
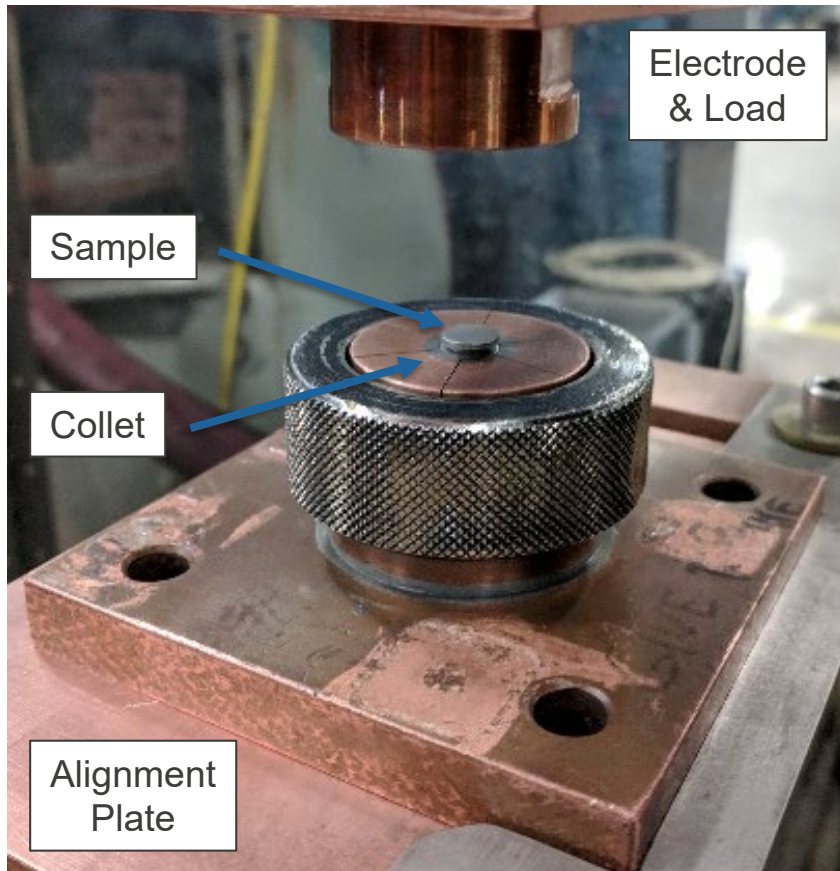
The projections in CDRW were adapted for joining cladding tubes to caps



Cross-section View

- Tube edge acts as our projection. Contacts cap chamfer for entire circumference
- Advantages:
 - Reduced machining costs, precision
 - Steep angle guides tube deformation
 - Material flowing/spattering back into tube captured in groove
- Disadvantages:
 - Lower tolerance for shape, diameter variations
 - Complicates removal of cold work

CDRW is controlled by complex interplays of load, peak current, and pulse duration

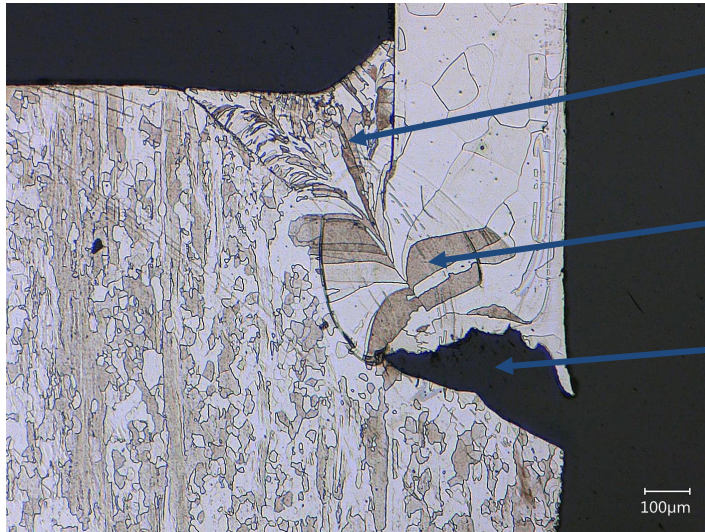


- Washer stack maintains sub-ms mechanical follow-up
- The deposited heat would be determined by peak current and pulse duration, but...
- The contact area is changed as load collapses the tube edge (projection), for a quench-like effect
- Connected with high- T and high- $\dot{\epsilon}$ flow, poorly understood

Several materials were joined in order to better bound the CDRW parameters

<u>Materials</u>		<u>Conditions</u>	
Ferritic Steel	430SS	Load	2 – 3 N
FeCrAl	B126Y Kanthal	Peak Current	15 – 30 kA
ODS	MA956	Duration	2 – 5 ms

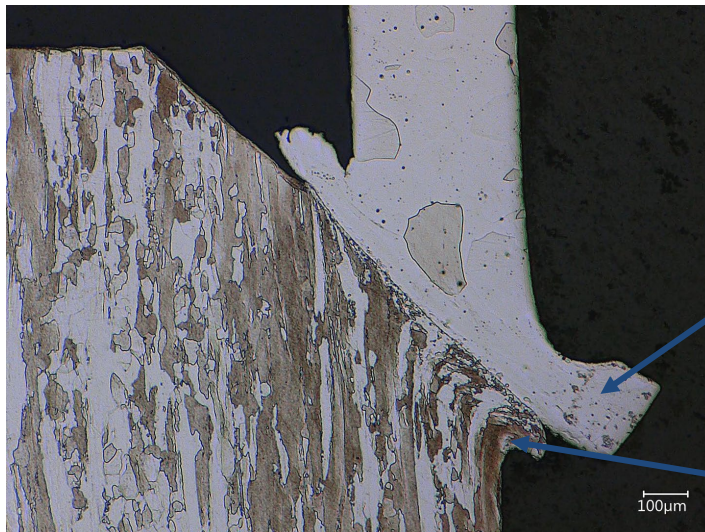
Weld conditions were rapidly screened using optical microscopy



Backflow
Into Tube

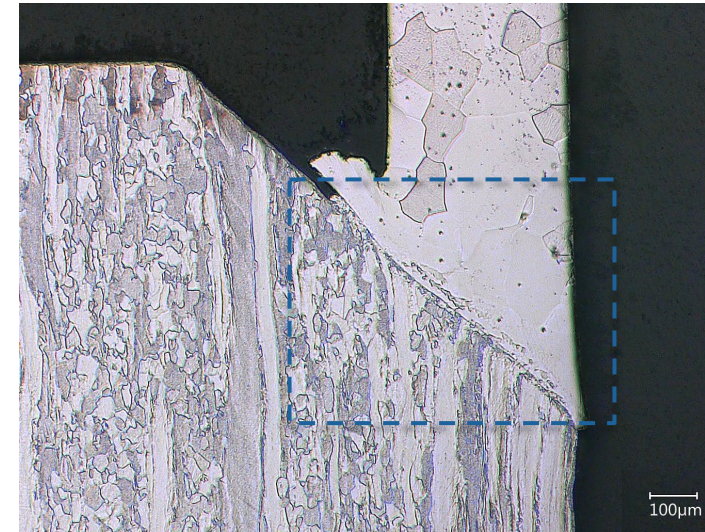
Resolidification
& Coarsening

Incomplete
Sealing

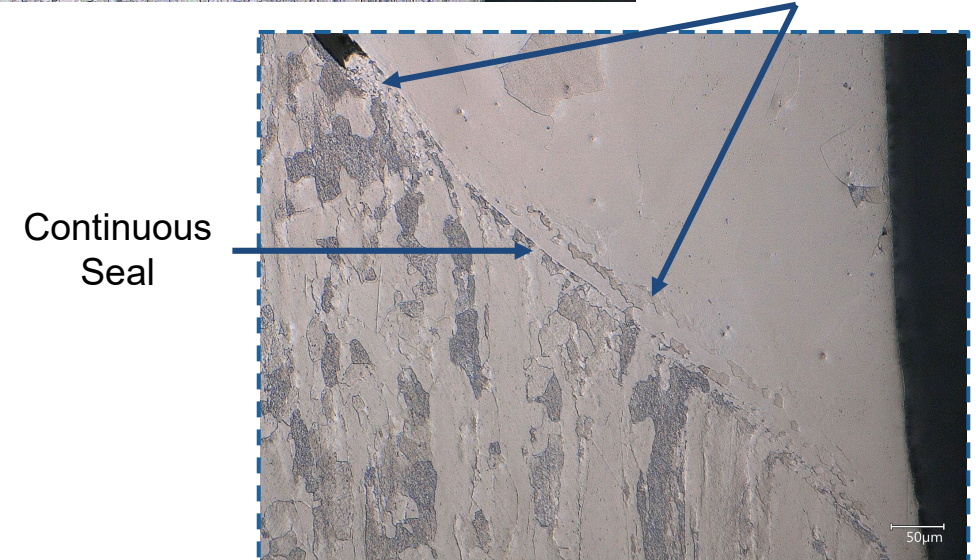


Loss of
Constraint

Excess Cap
Deformation

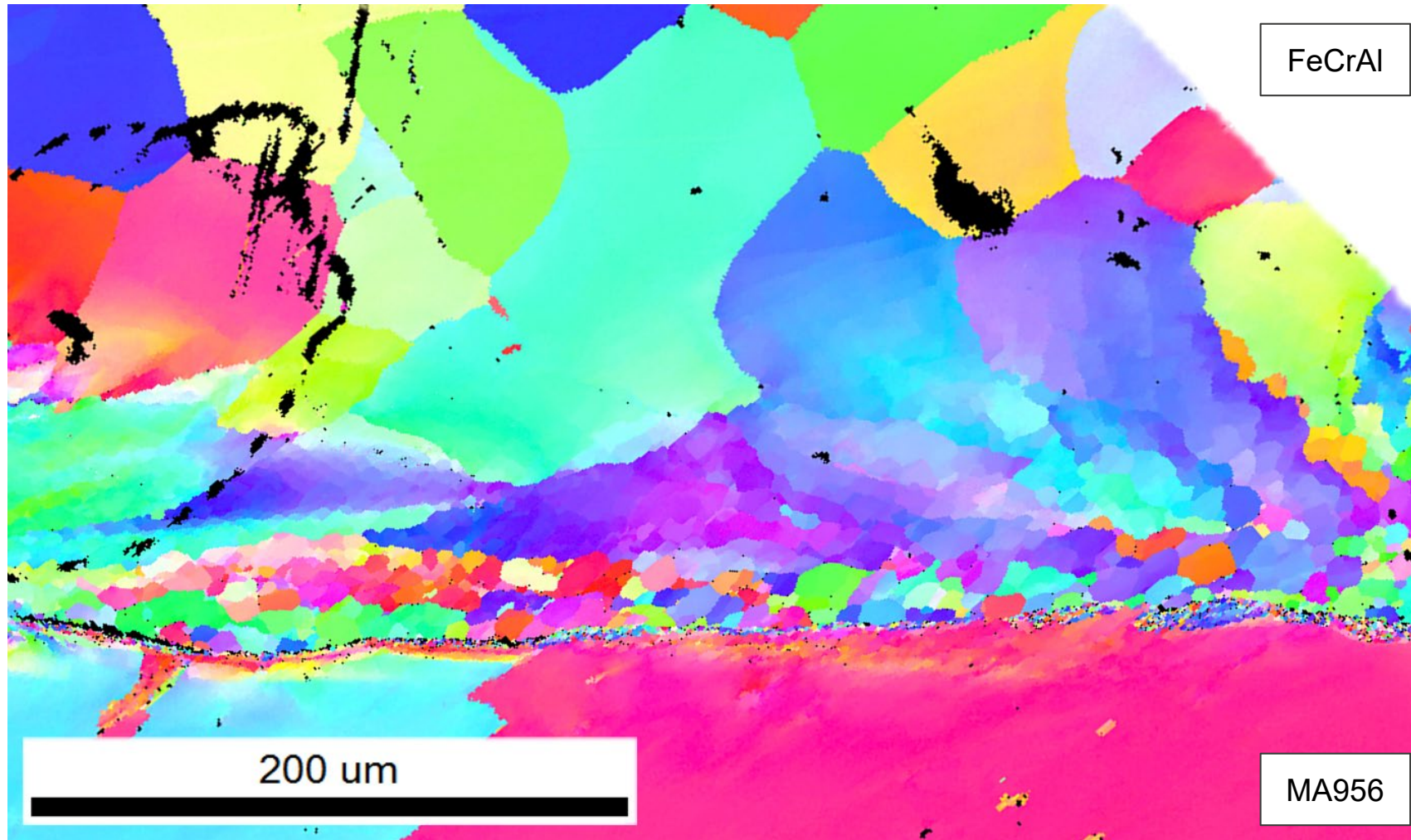


Dynamic
Recrystallization
at Interface



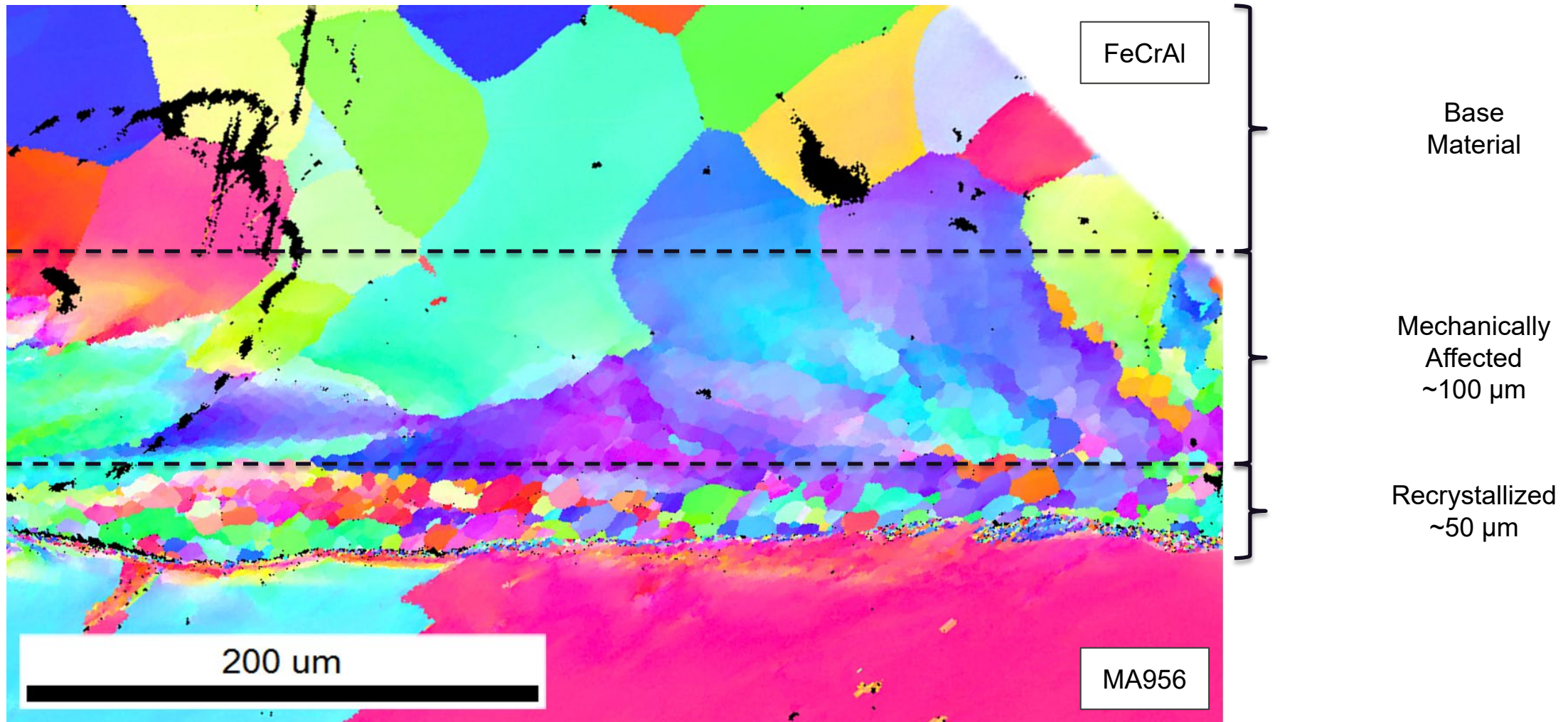
Continuous
Seal

Detailed microstructural analysis followed using EBSD



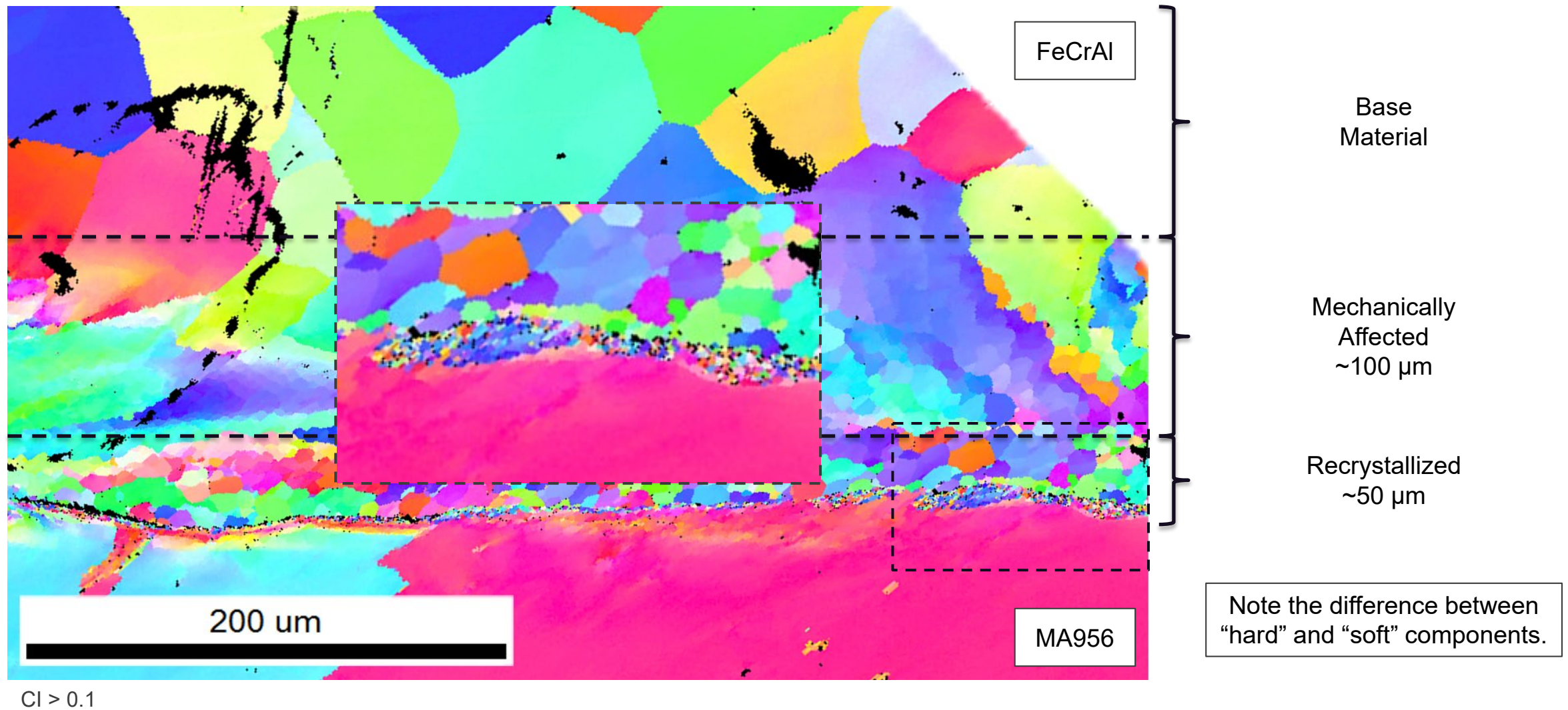
CI > 0.1

Detailed microstructural analysis followed using EBSD



CI > 0.1

Detailed microstructural analysis followed using EBSD



Analysis of similar and dissimilar joints leads to several key take-aways

1. No issues were observed with dissimilar materials – as expected given the lack of mixing
2. Only 1 in 25 welds was rejected for failure to seal, most issues arose from excess flow or constraint problems
3. The zones commonly seen in welded materials were either significantly reduced (~2x thinner) or absent in the CDRW joints
4. Joints between “hard” and “soft” components produced very different weld microstructure across the interface, which could result in issues for some combinations (e.g., hard-tube/soft-cap, refractory/non-refractory)

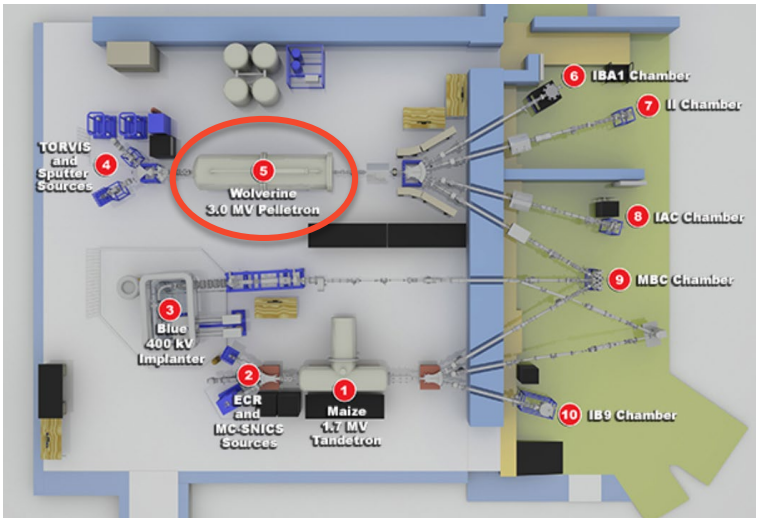
Accelerated irradiation testing was carried out using protons and heavy-ions

IBL
@ UW



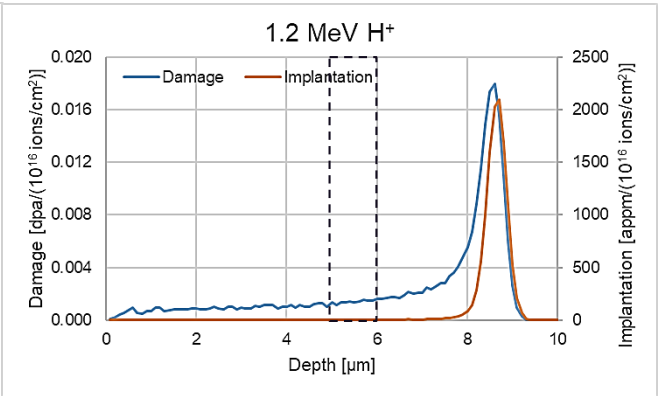
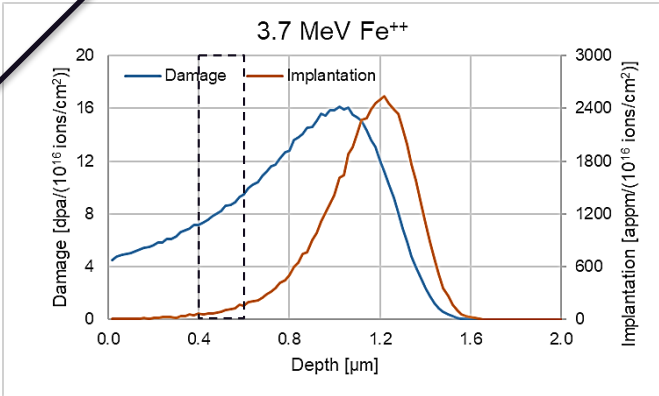
<https://ibl.ep.wisc.edu/>

MIBL
@ UM

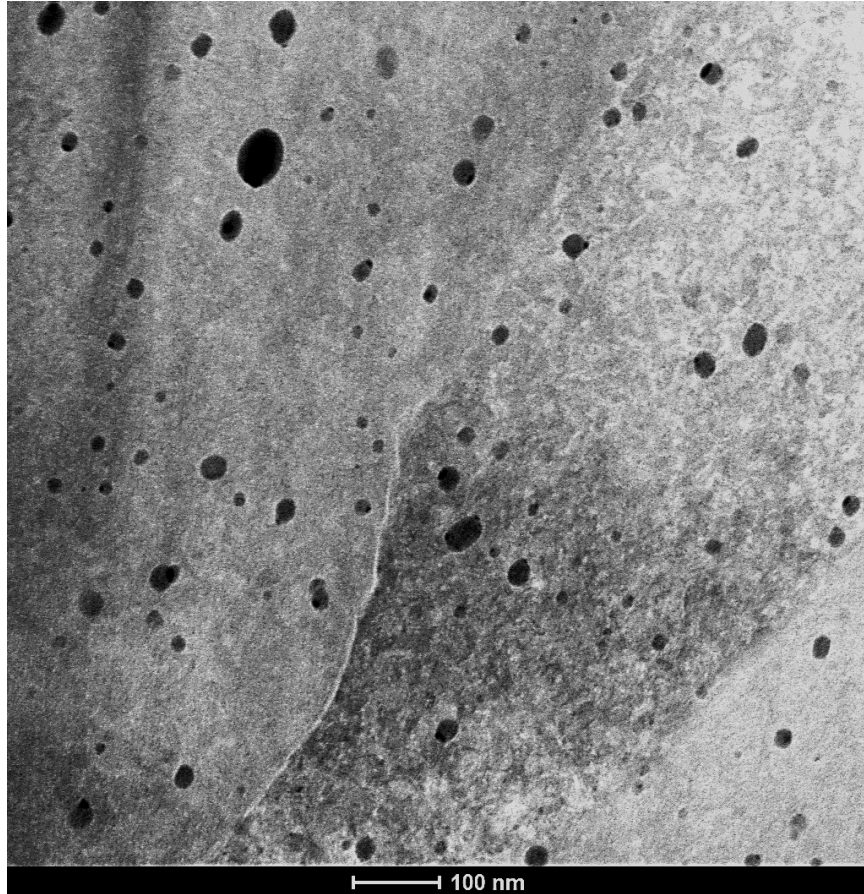


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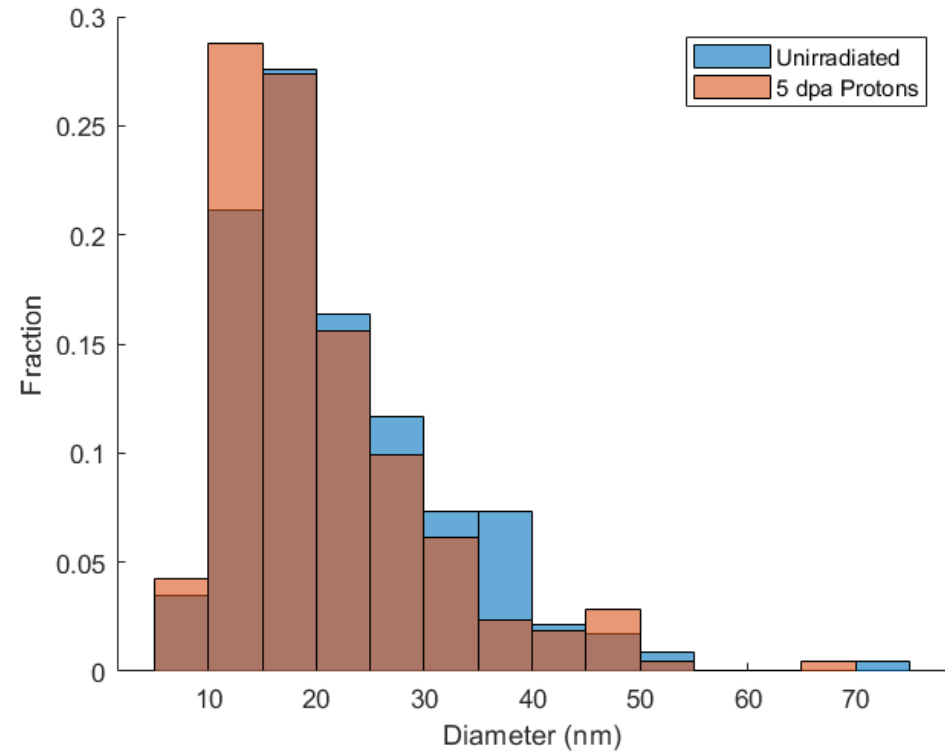
Interest	Ion	Temperature (°C)	Dose (dpa)
MS Swelling	3.7 MeV Fe ²⁺	350	10
			100
		450	10
			100
MS RIS	1.2 MeV H ⁺	360	1
			5



Preliminary characterization of proton irradiated joints revealed no significant change to oxides



HAADF of nanoparticles within 10 μm of weld, after 5 dpa irradiation



Unirradiated: 22.4 ± 1.2

5 dpa H^+ : 20.6 ± 1.3

Conclusions

- CDRW was used to join similar and differing ferritic alloys. Weld quality varied, but produced solidly bonded joints in most cases.
- CDRW joints showed considerably thinner – or absent – weld zones than more conventional techniques, suggesting that weld performance (e.g., strength, resistance to degradation) will be favorable. The thickness of recrystallized material, where it existed, increased at lower loads, higher peak currents, and longer pulse durations – as expected.
- Analysis of proton and heavy-ion irradiated samples is only beginning, but CDRW joined ODS material showed no significant changes to dispersed particles to 5 dpa.
- Future work in this line will focus on additional ODS materials (i.e., 14YWT) and include additional, time prohibited testing of the welds (e.g., He leak, nano-/mesoscale mechanical).