Quantification of the Role of Interfaces and Grain Boundaries in the Development of Radiation Tolerant Nuclear Materials

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Pranav K. Suri, James E. Nathaniel, Mitra L. Taheri
Drexel University

Yongqiang Wang, Jon K. Baldwin, Nan Li
Los Alamos National Laboratory

Khalid Hattar
Sandia National Laboratories

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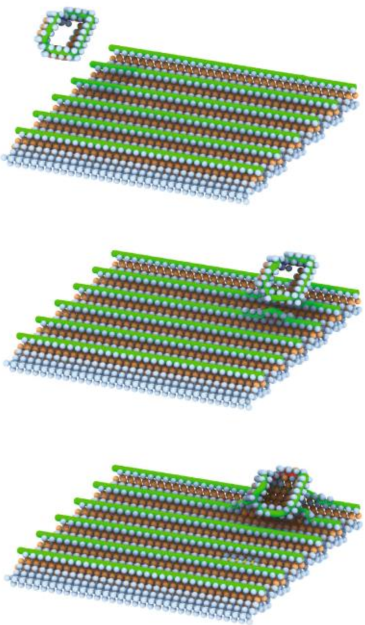
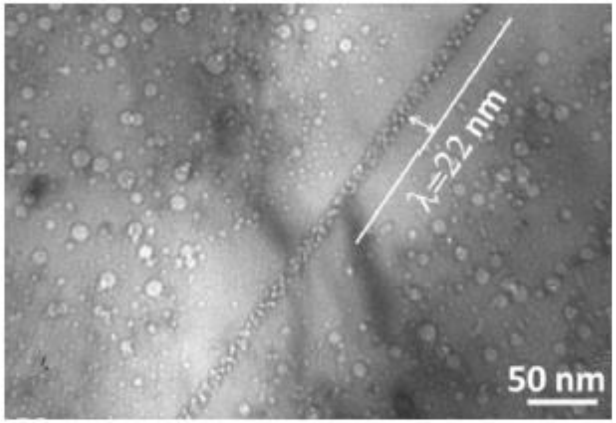
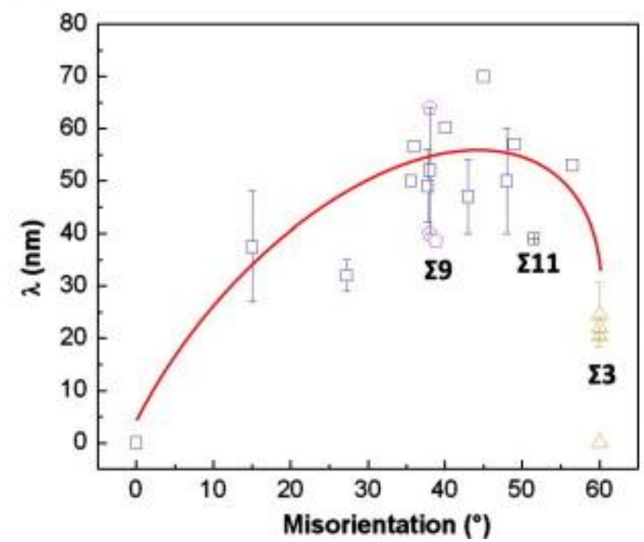
Background

- Interfaces act as sinks for defects → more defect absorption is expected when more interfaces are present. Therefore, nanocrystalline materials seems to be ideal candidates for enhanced radiation tolerant nuclear materials







- Defect-interface interactions depend heavily on the atomic structure at the interface

W. Han, M. Demkowicz, E. Fu, Y. Wang, A. Misra, Acta Materialia 60(18) (2012) 6341
B.P. Uberuaga, L.J. Vernon, E. Martinez, A.F. Voter, Scientific Reports 5 (2015) 9095
C. Jiang, N. Swaminathan, J. Deng, D. Morgan, I. Szlufarska, Materials Research Letters 2(2) (2014) 100
E. Martínez, B.P. Uberuaga, I.J. Beyerlein, JOM 68(6) (2016) 1616

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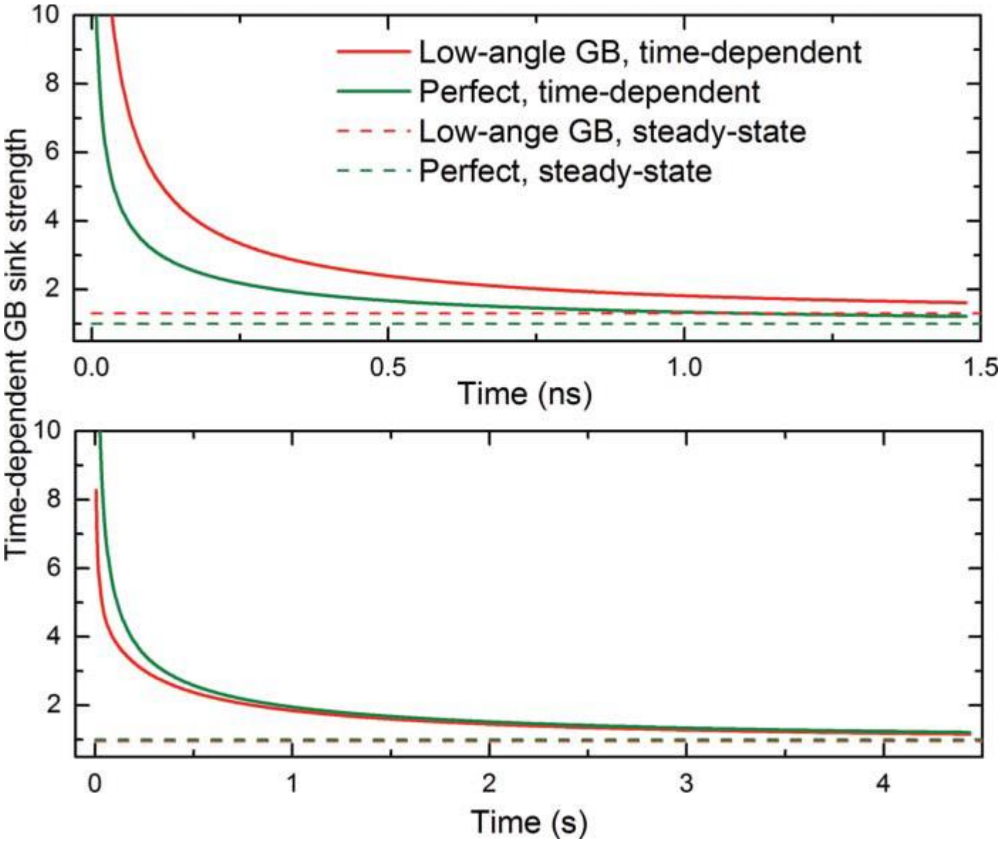
Background

- Microstructure of interface keeps changing with defect absorption and therefore interfaces are not static entities in extreme conditions like irradiation



W. Han, M. Demkowicz, E. Fu, Y. Wang, A. Misra, Acta Materialia 60(18) (2012) 6341
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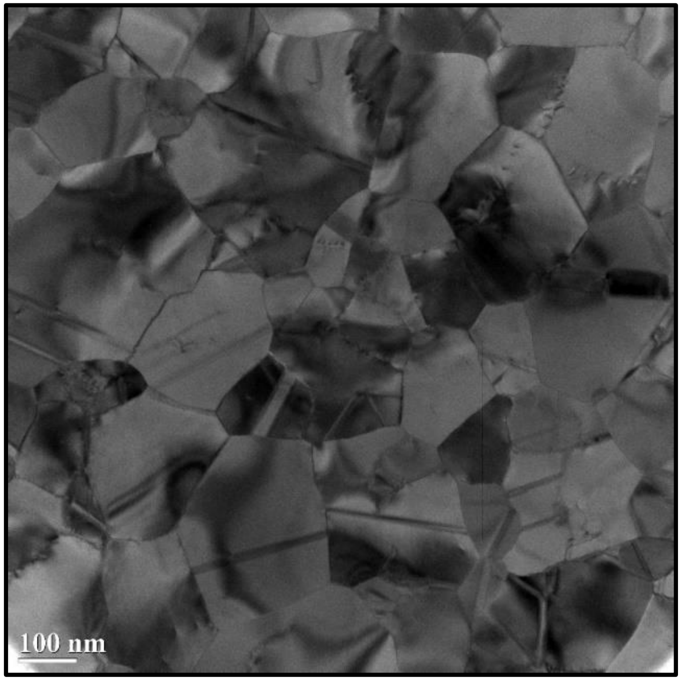
C. Jiang, N. Swaminathan, J. Deng, D. Morgan, I. Szlufarska, Materials Research Letters 2(2) (2014) 100
E. Martínez, B.P. Uberuaga, I.J. Beyerlein, JOM 68(6) (2016) 1616

Motivation

- Can we quantitatively characterize the dynamic evolution of interfaces with damage?
- Can we quantify the intake of defects in the interfaces with damage?
- What is the role of grain boundary (GB) character and interfacial strain towards defect absorption?

Nanocrystalline Pure Phase



Au (FCC) : a model system

I. Beyerlein, M. Demkowicz, A. Misra, B. Uberuaga, Progress in Materials Science 74 (2015) 125
B.P. Uberuaga, L.J. Vernon, E. Martinez, A.F. Voter, Scientific Reports 5 (2015) 9095
C. Jiang, N. Swaminathan, J. Deng, D. Morgan, I. Szlufarska, Materials Research Letters 2(2) (2014) 100

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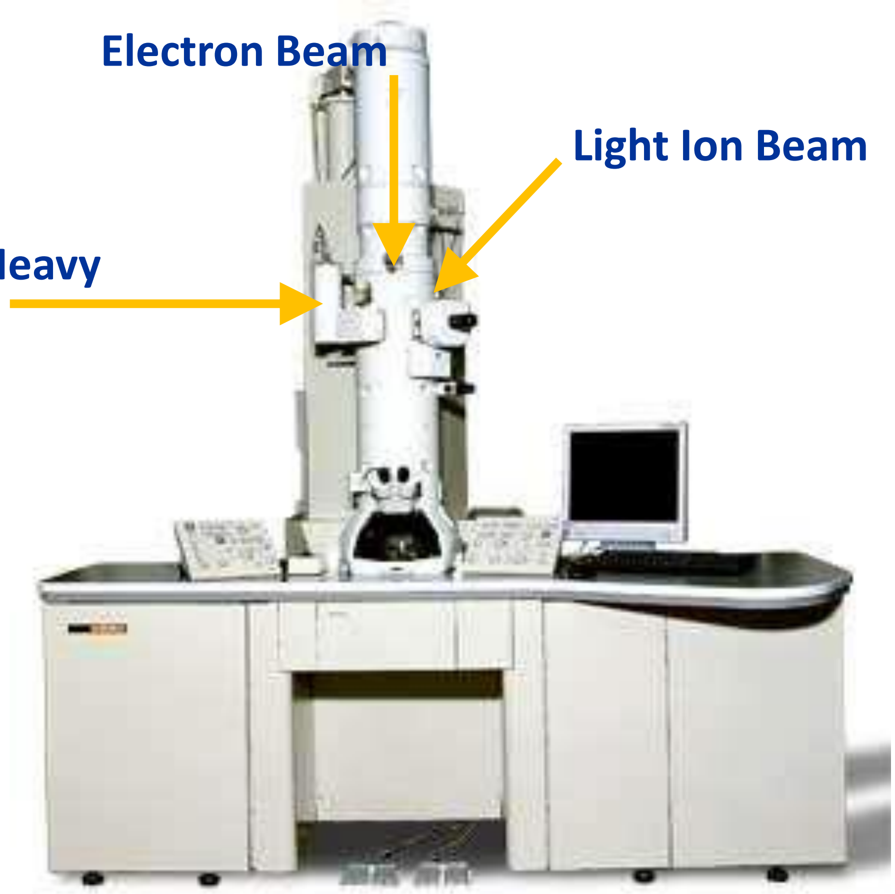
Research Techniques

In-situ Ion Irradiation Transmission Electron Microscopy (I3TEM)

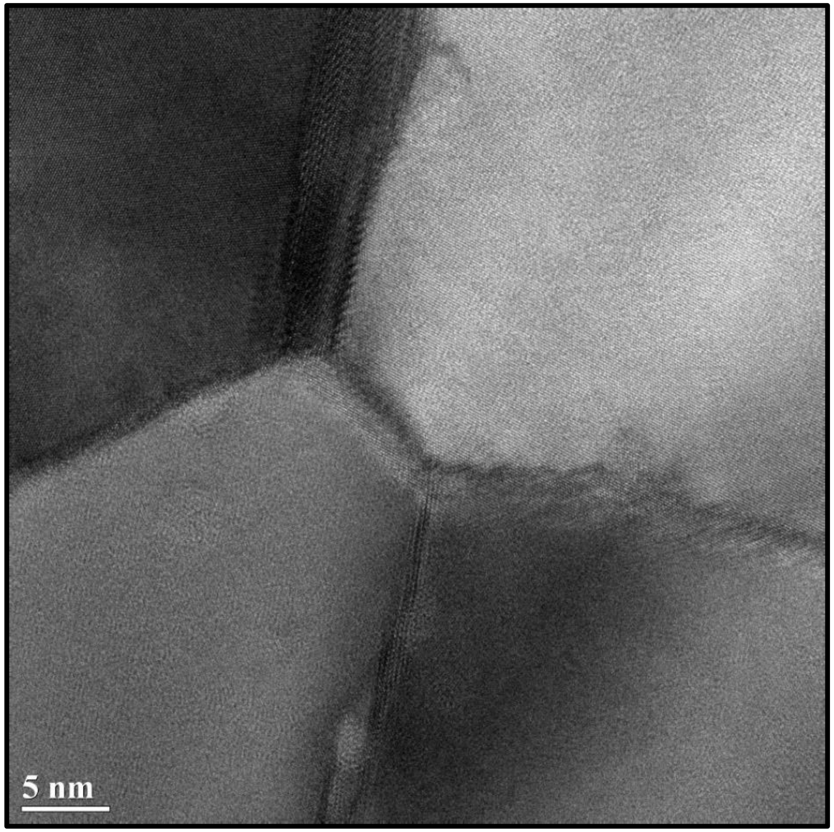


Watch radiation damage in real-time

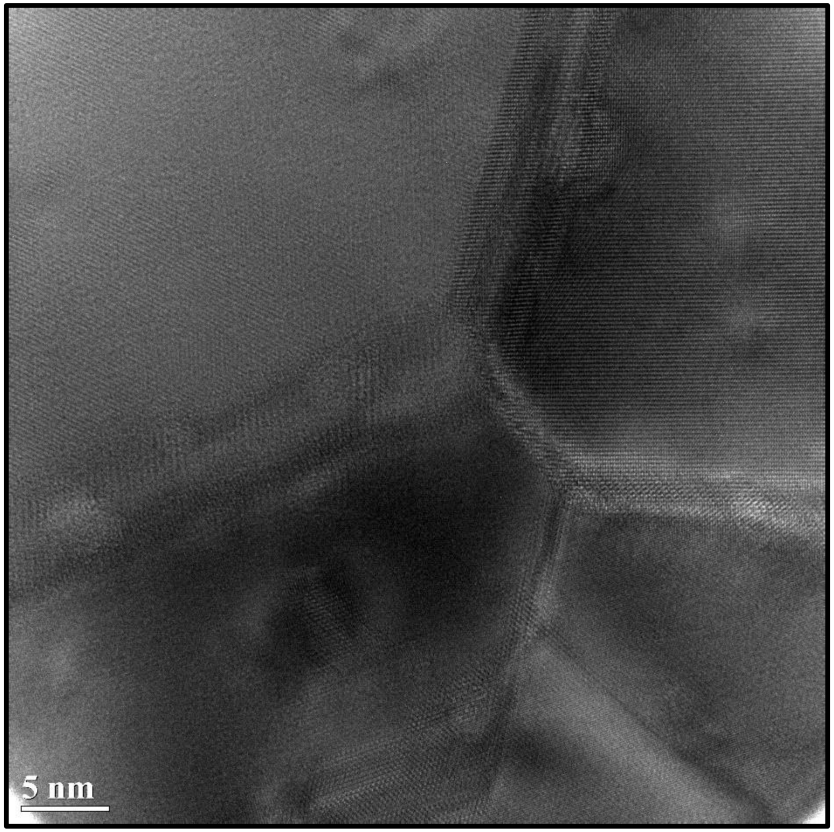
Research Techniques

Atomic-Resolution TEM Imaging

Pre-irradiation



Post-irradiation

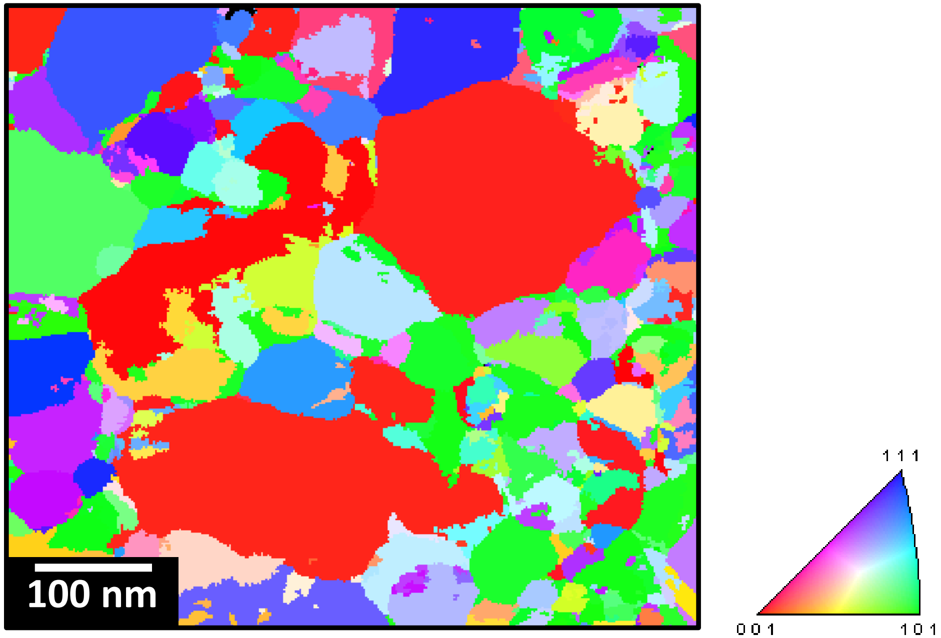


Characterize the atomic-structure changes

Research Techniques

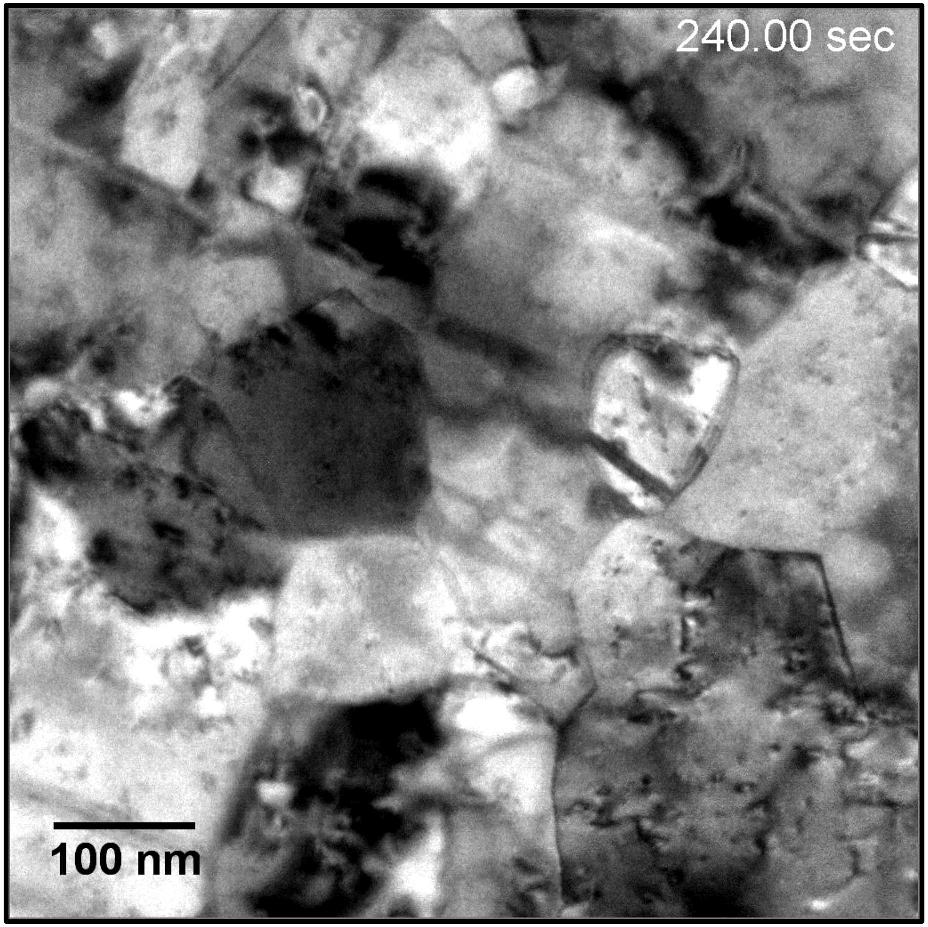
Precession Electron Diffraction

Measure GB character and crystal misorientation across interface



Time Dependent Radiation Response

Nanocrystalline Au



2.8 MeV Au^{+4} at 200 °C
Flux = 1.86 × 10^{11} ions/cm^2/s
Time step = 0.60 s
Time zero = 0 dpa

A representative video showing evolution of defects with radiation damage

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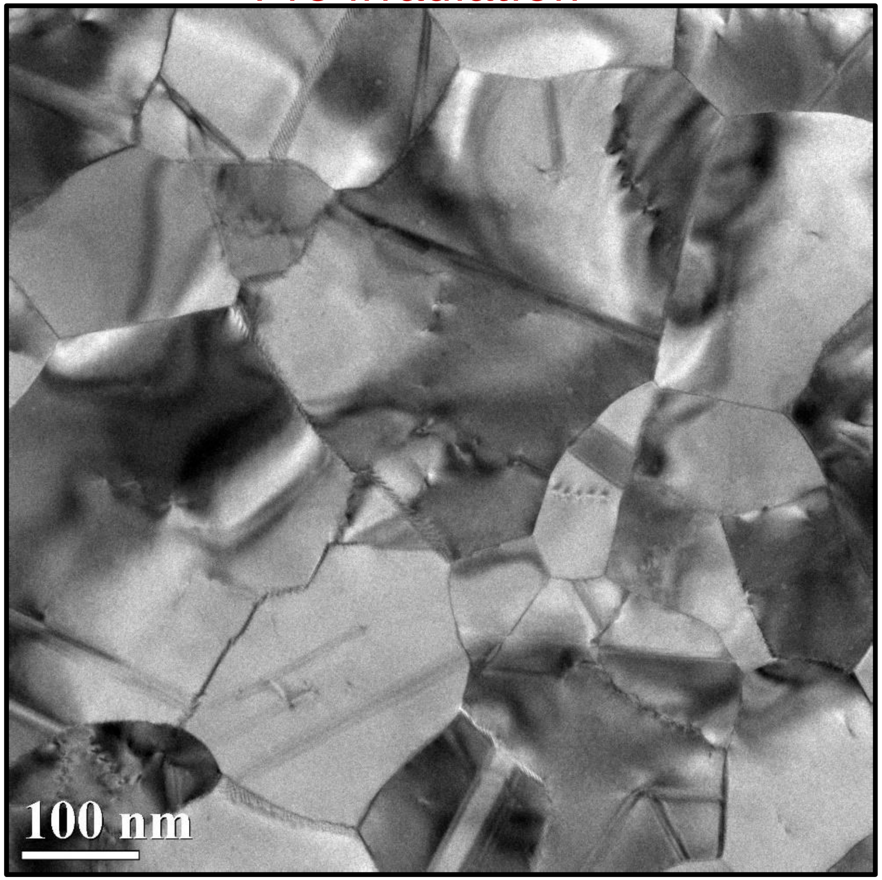
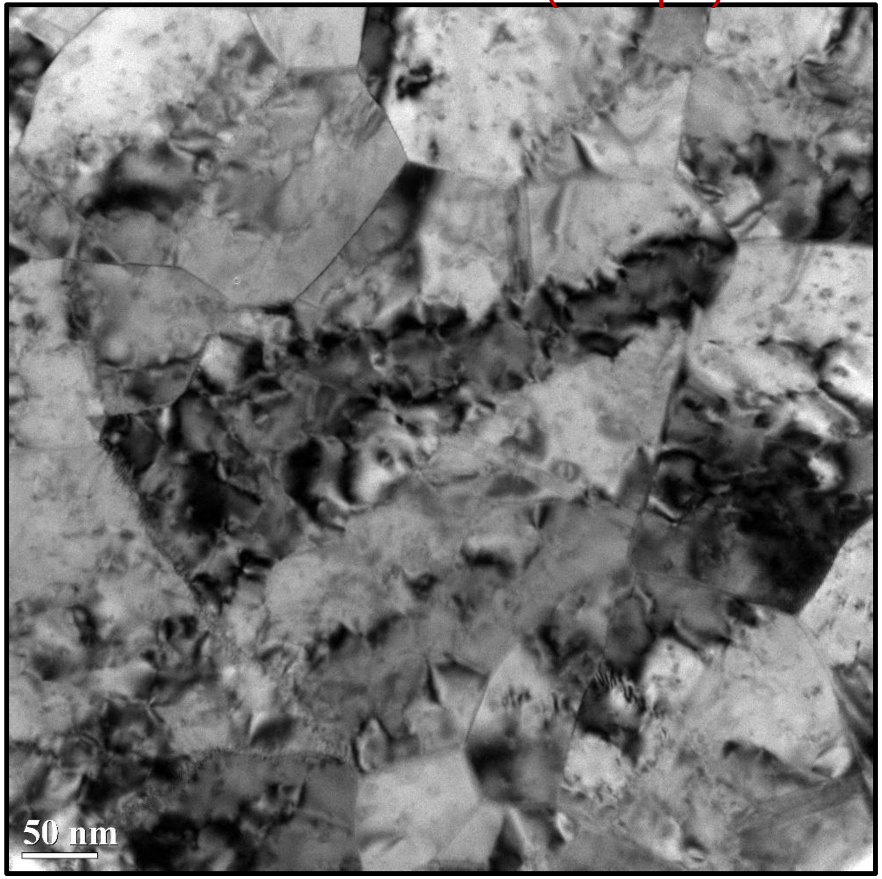
Understanding Radiation Response at GBs

Nanocrystalline Au

Pre-irradiation



Post-irradiation (10 dpa)

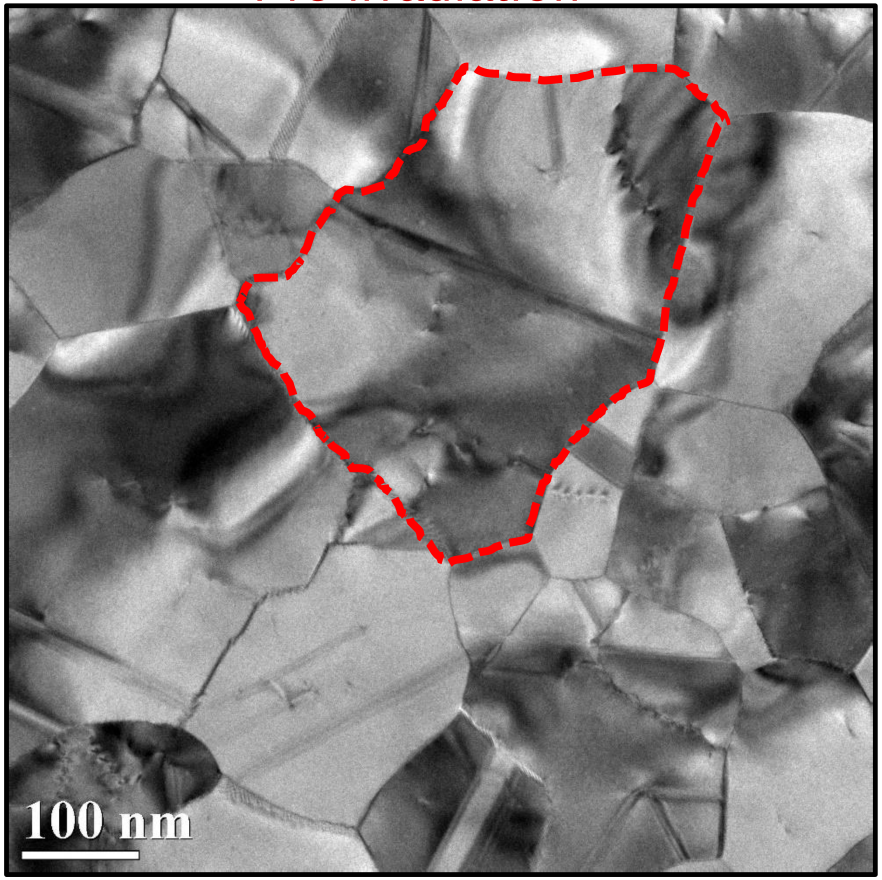


Microstructure and diffraction contrast changes after radiation damage

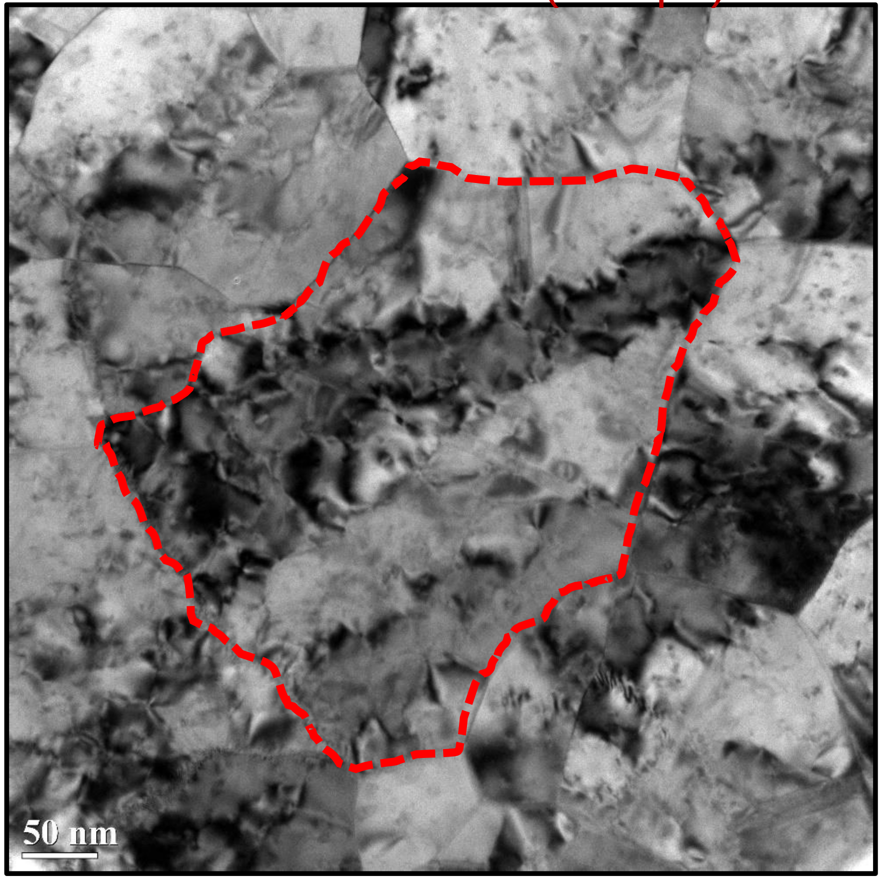
Understanding Radiation Response at GBs

Nanocrystalline Au

Pre-irradiation



Post-irradiation (10 dpa)



Microstructure and diffraction contrast changes after radiation damage

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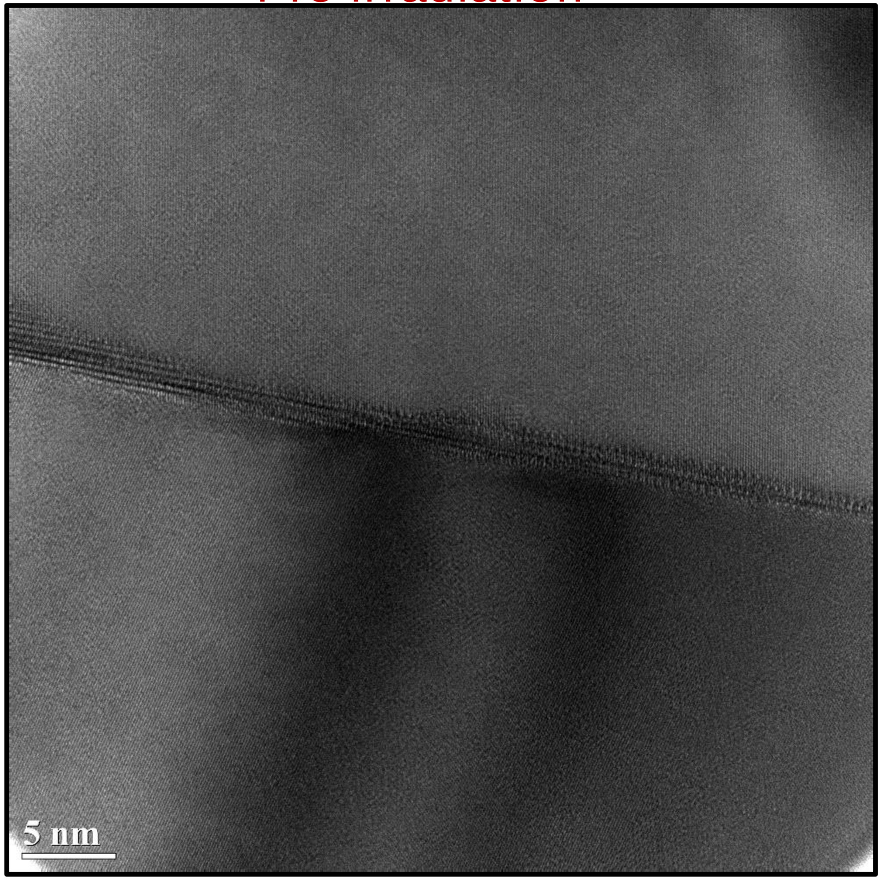
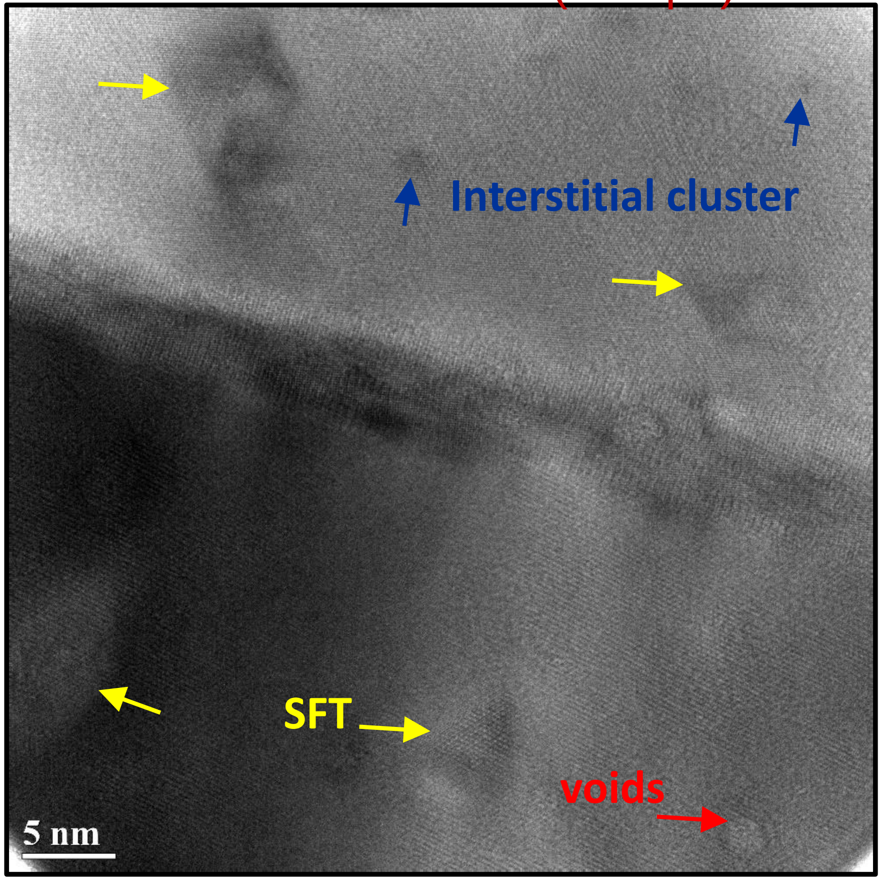
Understanding Radiation Response at GBs

Nanocrystalline Au

Pre-irradiation



Post-irradiation (10 dpa)



Formation of radiation induced voids, interstitial clusters and SFT near GBs

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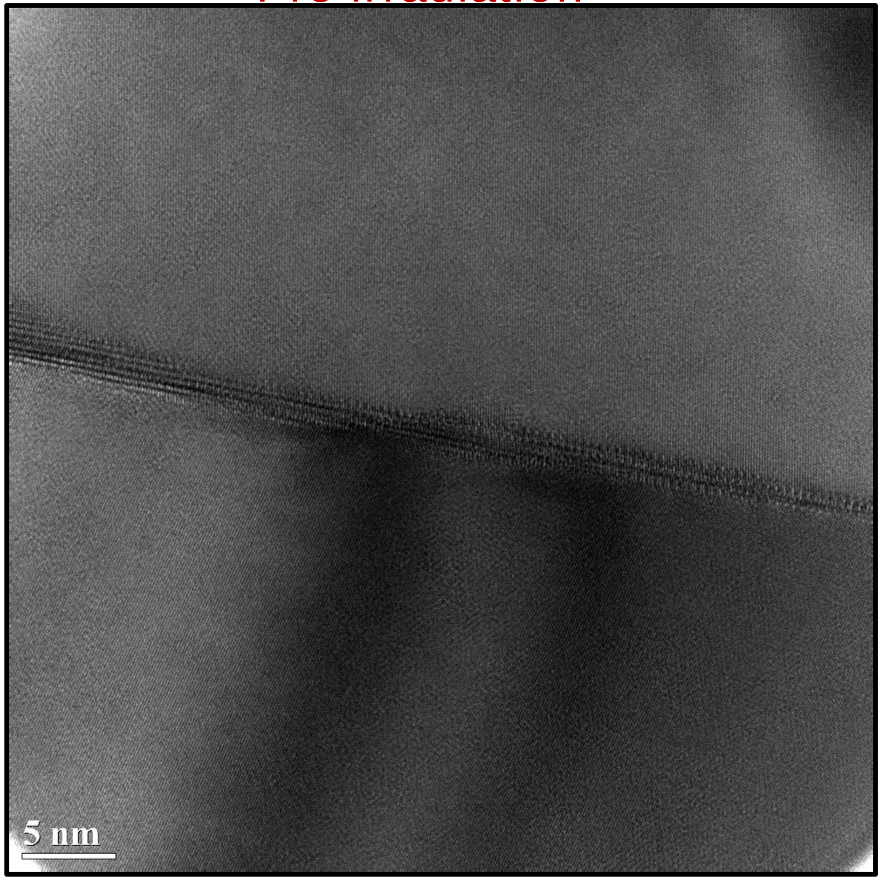
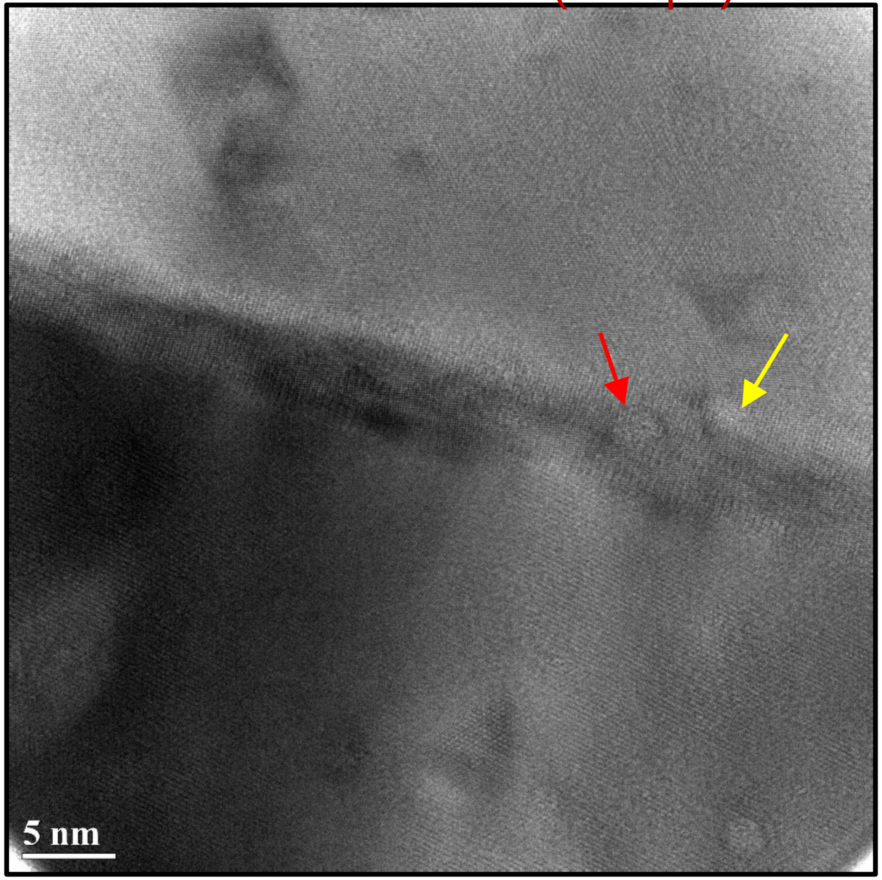
Understanding Radiation Response at GBs

Nanocrystalline Au

Pre-irradiation



Post-irradiation (10 dpa)



Defect absorption at GB and increase in GB width → GB structure modification

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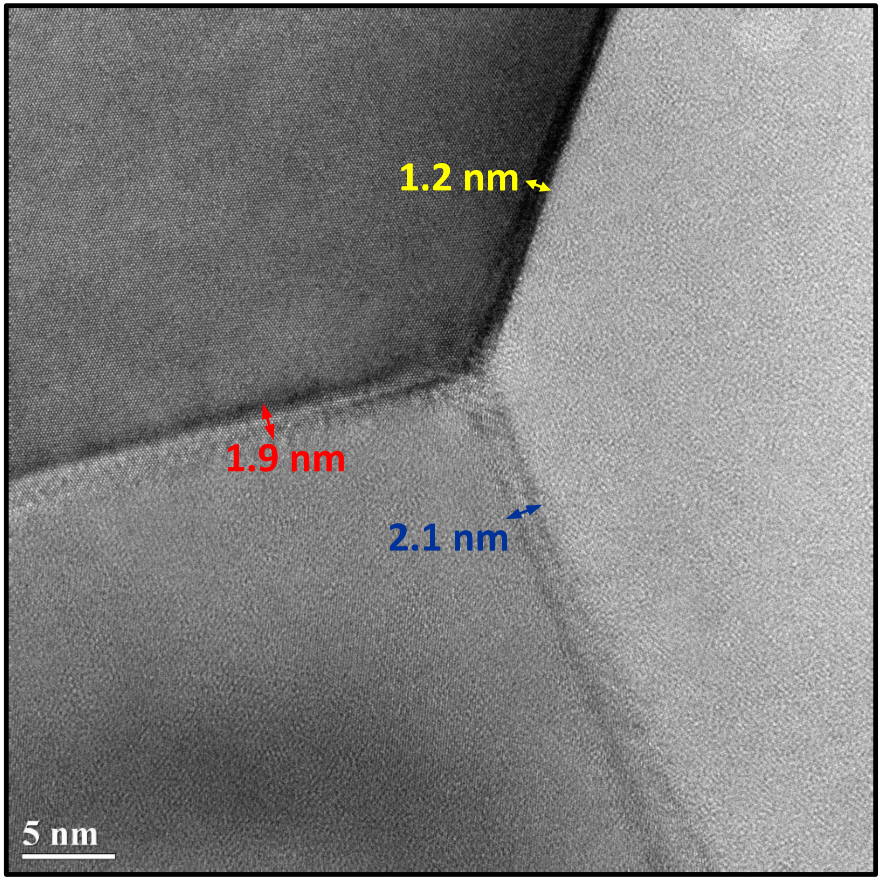
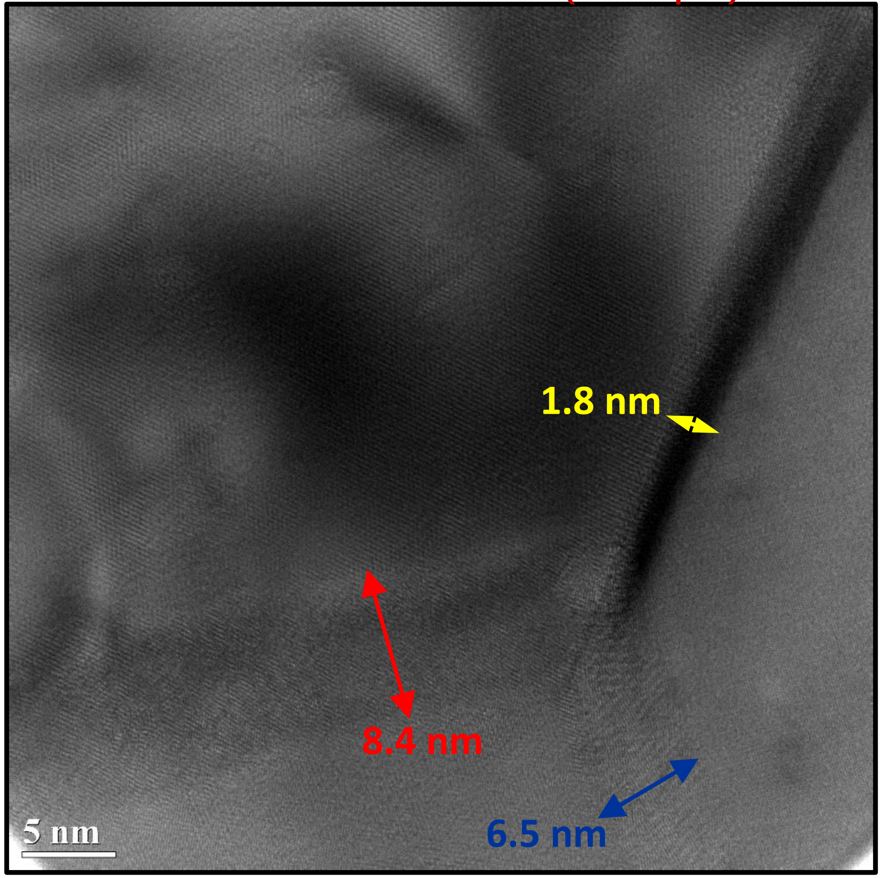
Quantification of Radiation Response at GBs

Nanocrystalline Au (near Triple Point)



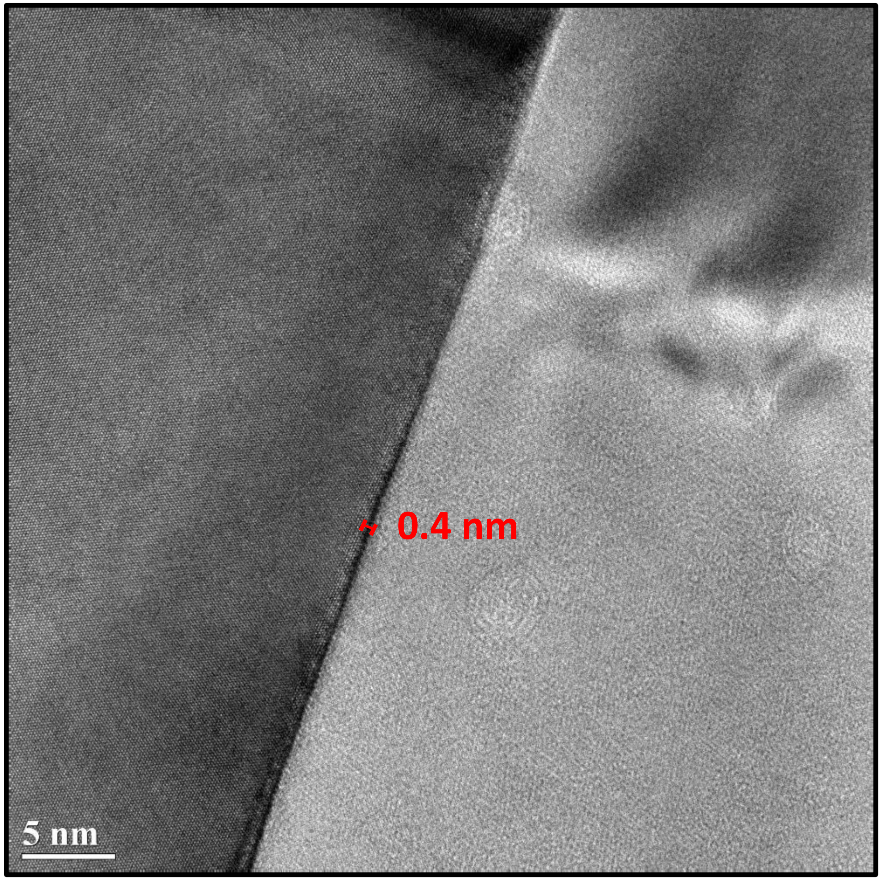


Amount of change in GB width is unique for each interface

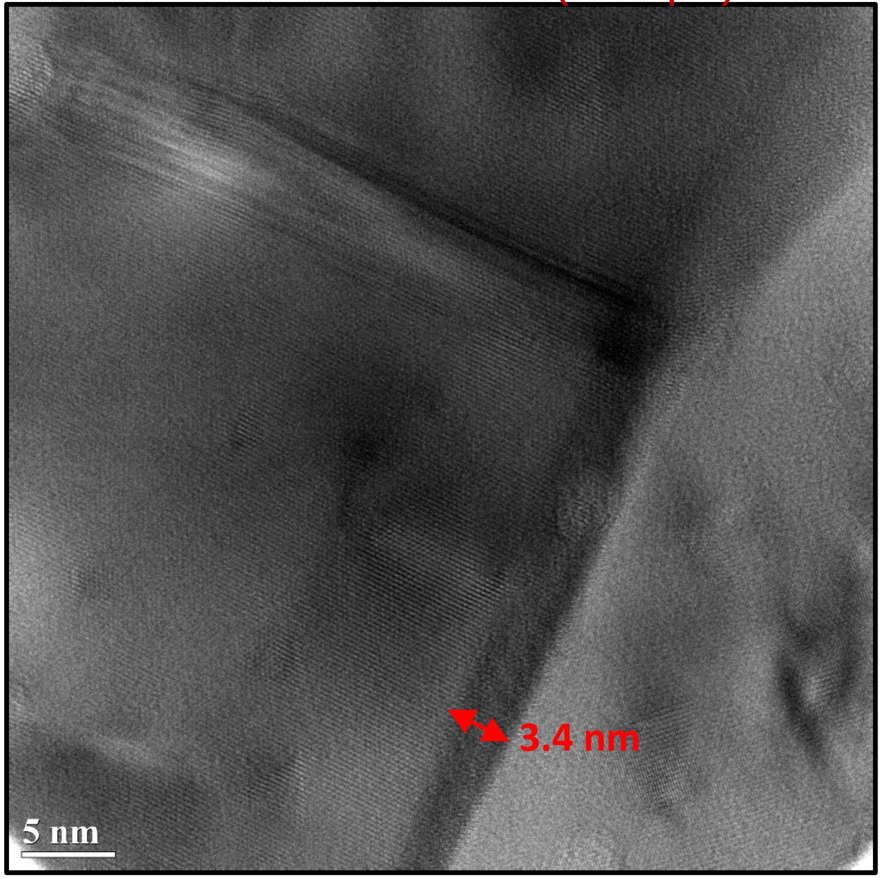
Quantification of Radiation Response at GBs

Nanocrystalline Au (near Twin Boundary)

Pre-irradiation



Post-irradiation (10 dpa)

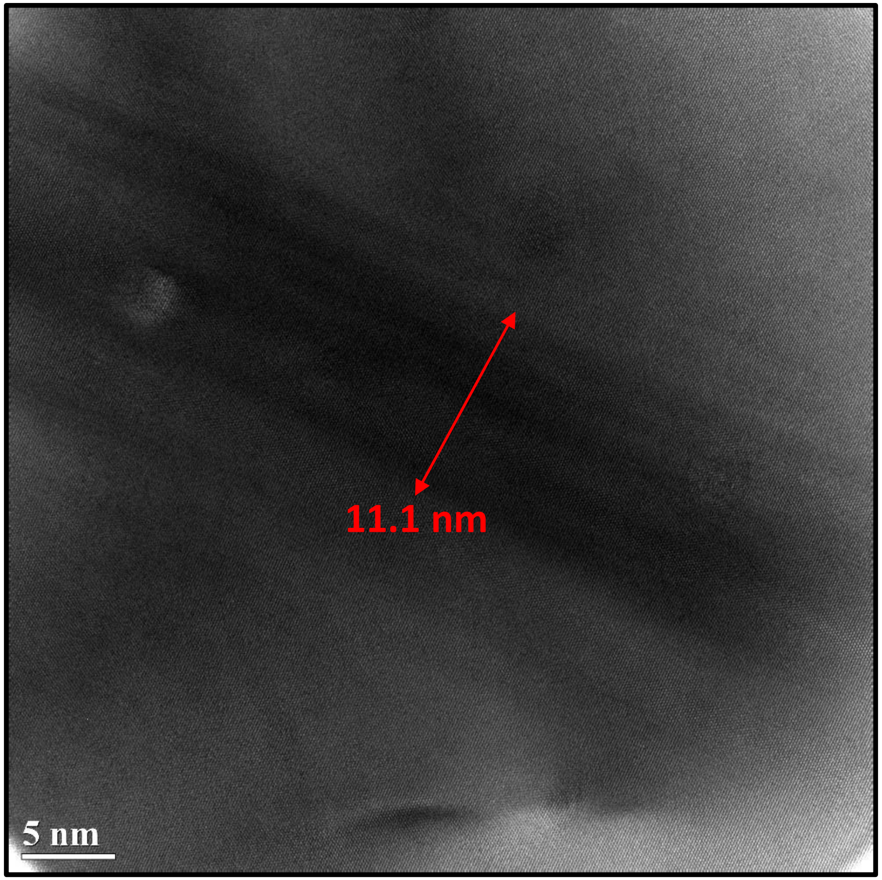


Amount of change in GB width is unique for each interface

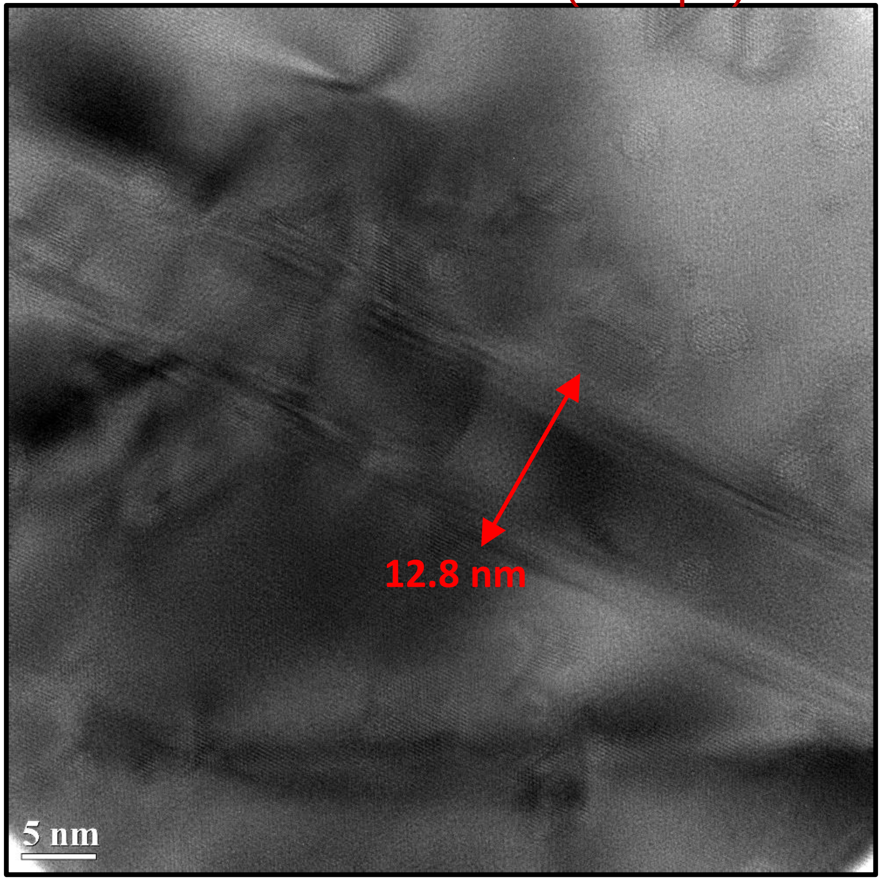
Quantification of Radiation Response at GBs

Nanocrystalline Au (at Twin Boundary)

Pre-irradiation



Post-irradiation (10 dpa)



Twin boundary seems to be more resistant to defect absorption

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Summary

- Showed a protocol to quantify the radiation response of interfaces using in-situ and atomic-resolution electron microscopy

- Showed that different interfaces behave differently to the radiation response and hence absorb different amount of defects

- Twin boundary seems to be more resistant to defect mitigation of radiation induced defects

- There exists an optimum radiation dose after which interfaces should saturate and hence leading to formation of denuded zones

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Outlook

- Understand why different interfaces have different radiation response
- Quantify the saturation limit for each type of interface
- Understand the role of interfacial strain in defect mitigation

Acknowledgements

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- Collaborators
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- MRS Symposium organizers

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