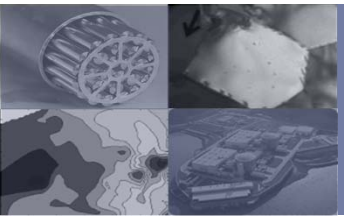


Nuclear Materials Research Group
Department of Mechanical and Materials Engineering

Queen's University

Effect of proton irradiation on the mechanical property change of Zircaloy-2 alloy

Fei Long, Zhongwen Yao, Mark Daymond

Department of Mechanical and Materials Engineering,
Queen's University, Kingston, ON, Canada

Outline

I. Materials and irradiation conditions

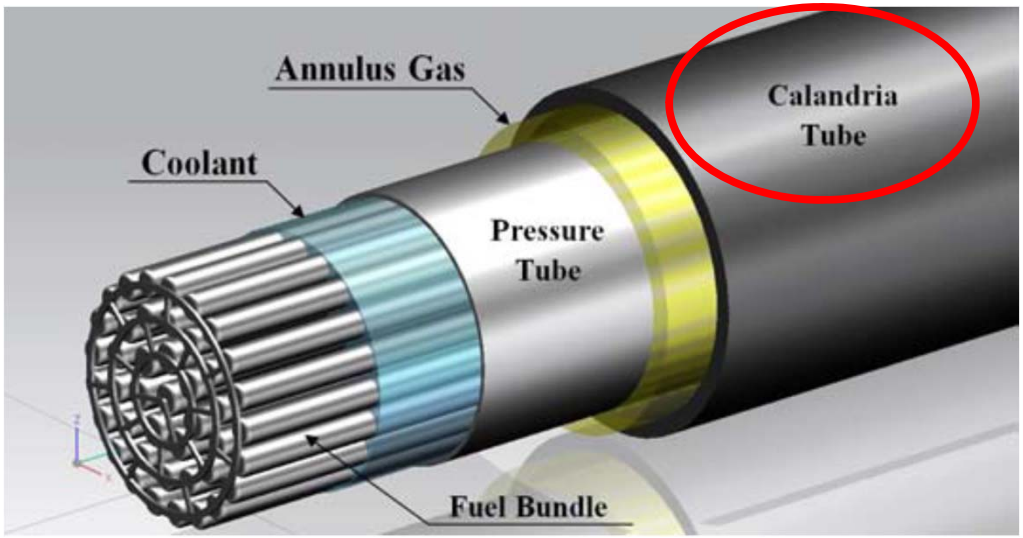
II. Experimental results

- Irradiation generated defects
- Change of nano-indentation hardness upon irradiation
- Effect of irradiation on the tensile strength

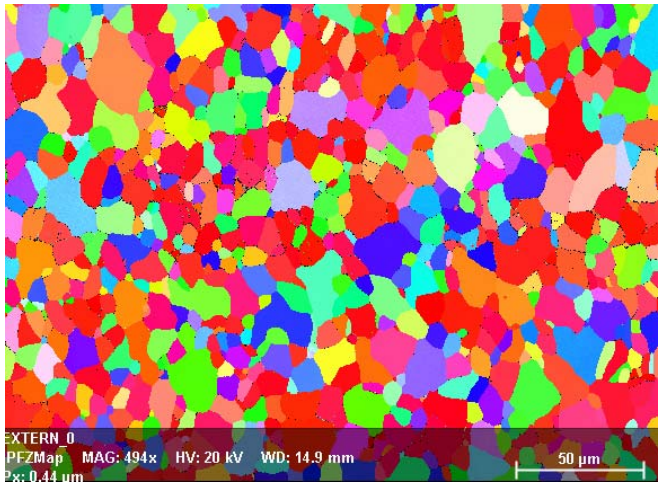
III. Conclusion

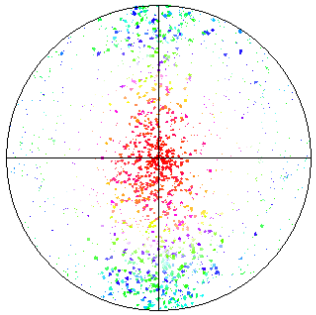
Materials

CANDU-reactor fuel channel components*



Annealed Zircaloy-2 plate with 1.5mm thickness



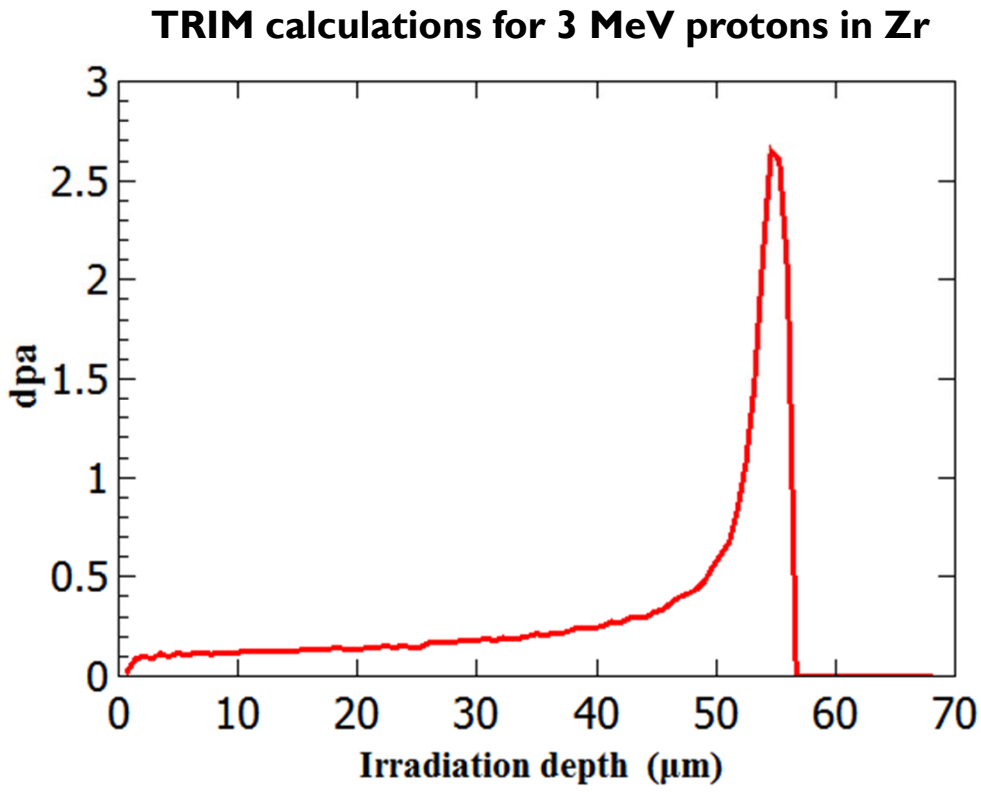


(0002) pole figure

* L. Grande, etc., Proceedings of the 18th International Conference on Nuclear Engineering

Irradiation condition

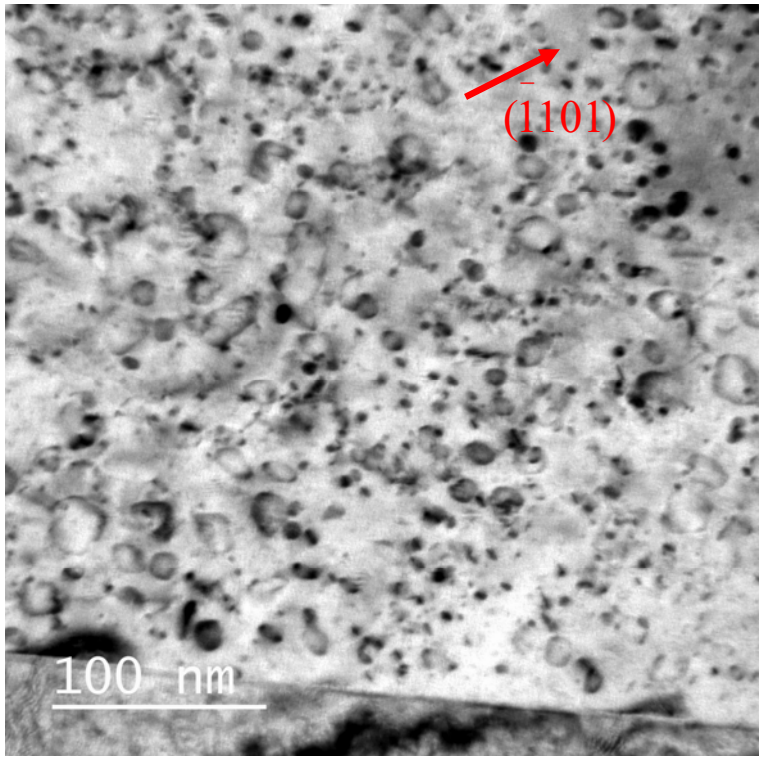
- **Proton beam energy**: 3MeV
- **Irradiation temperature**: 180°C
- **Irradiation area**: 15mm×15mm
- **Irradiation dose**: 0.114 dpa at 1.94×10^{-6} dpa/s (20μAmps current on the whole irradiated area)



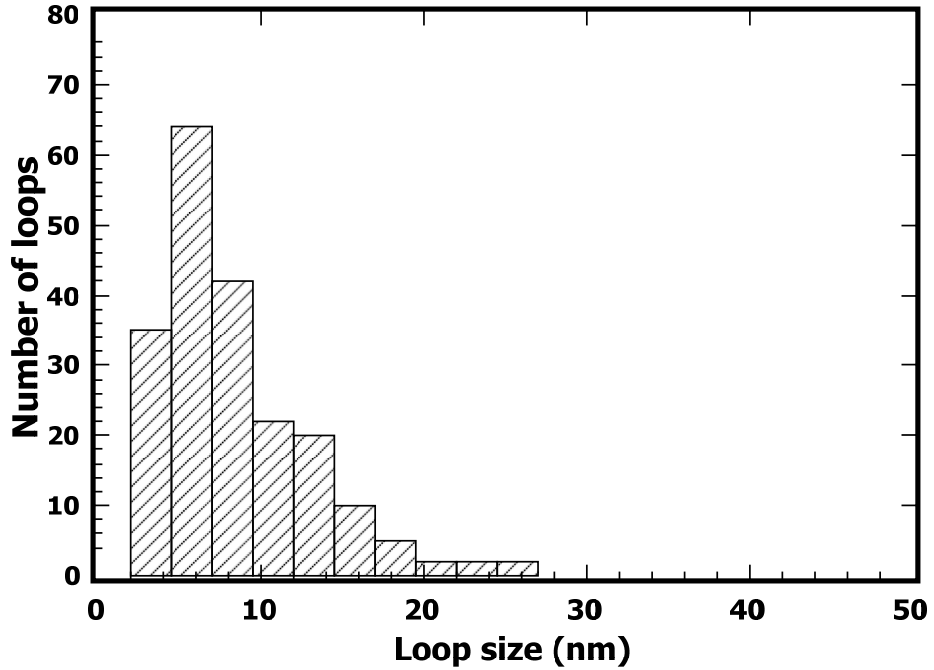
Experimental results

- Irradiation generated defects (dislocation loops)
- Change of nano-indentation hardness upon irradiation
- Effect of irradiation on the yield strength

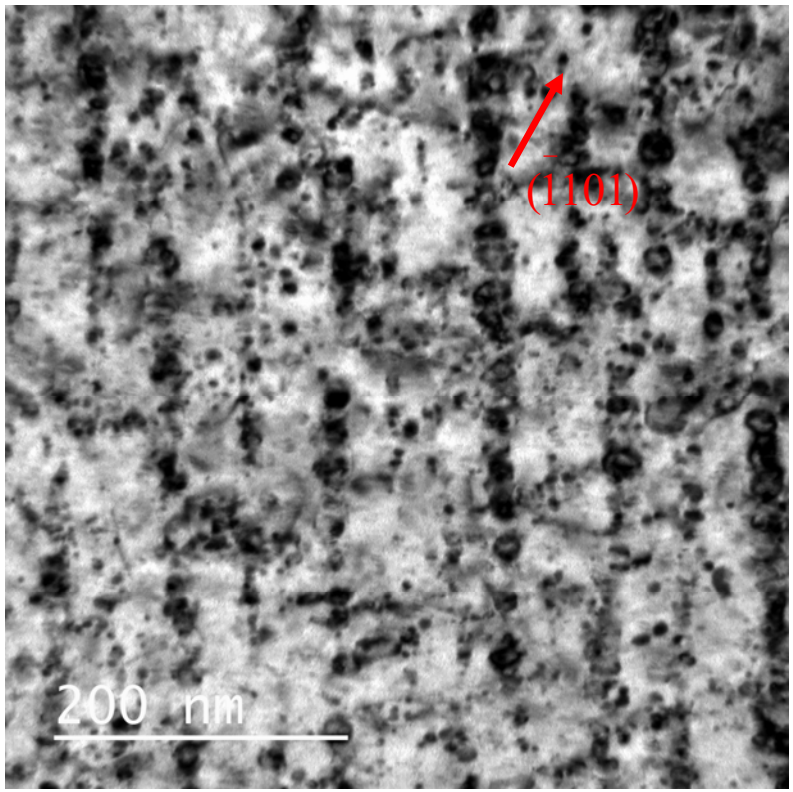
Irradiation generated defects (dislocation loops)

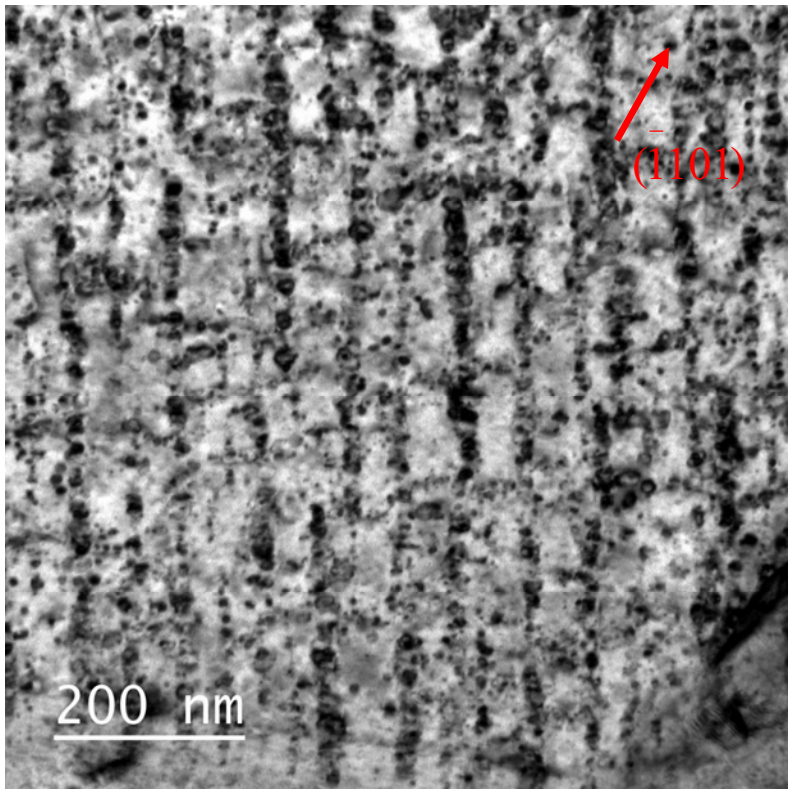


$[10\bar{1}1]$ zone axis



Irradiation generated defects (dislocation loops)

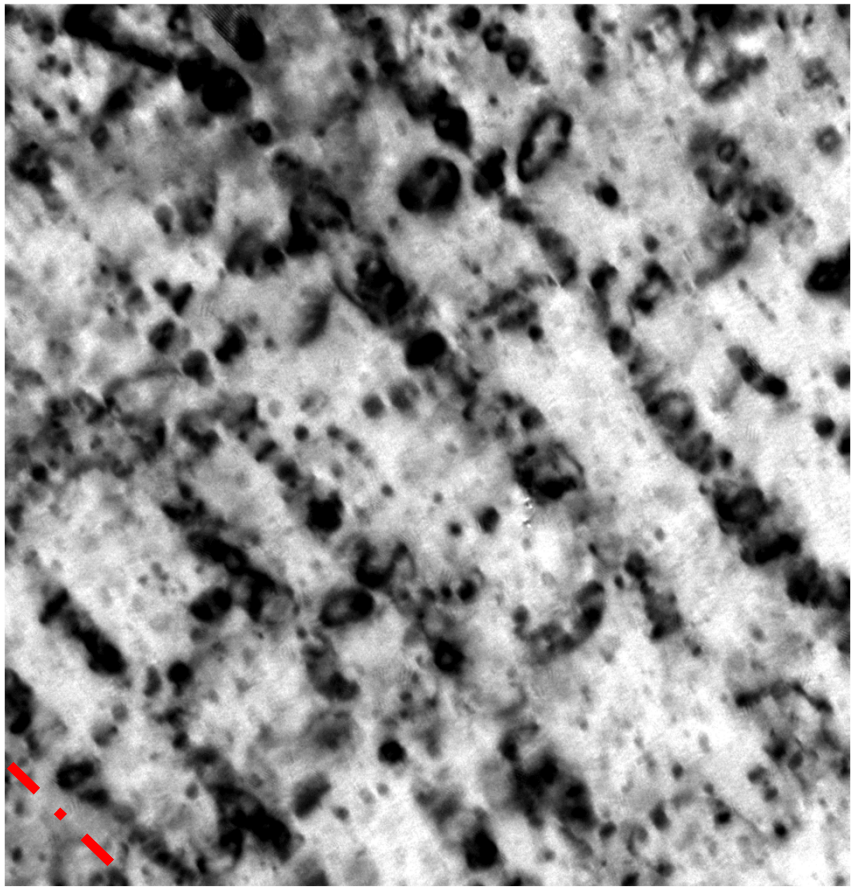




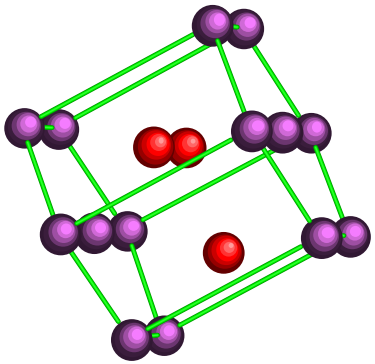
(0002) basal plane trace

$[11\bar{2}0]$ zone axis

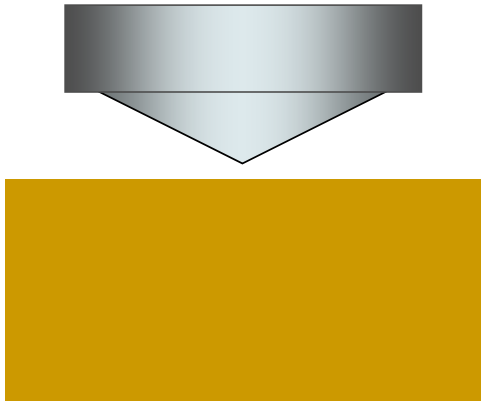
Irradiation generated defects (dislocation loops)



(0002) basal plane trace



Nano-indentation hardness test



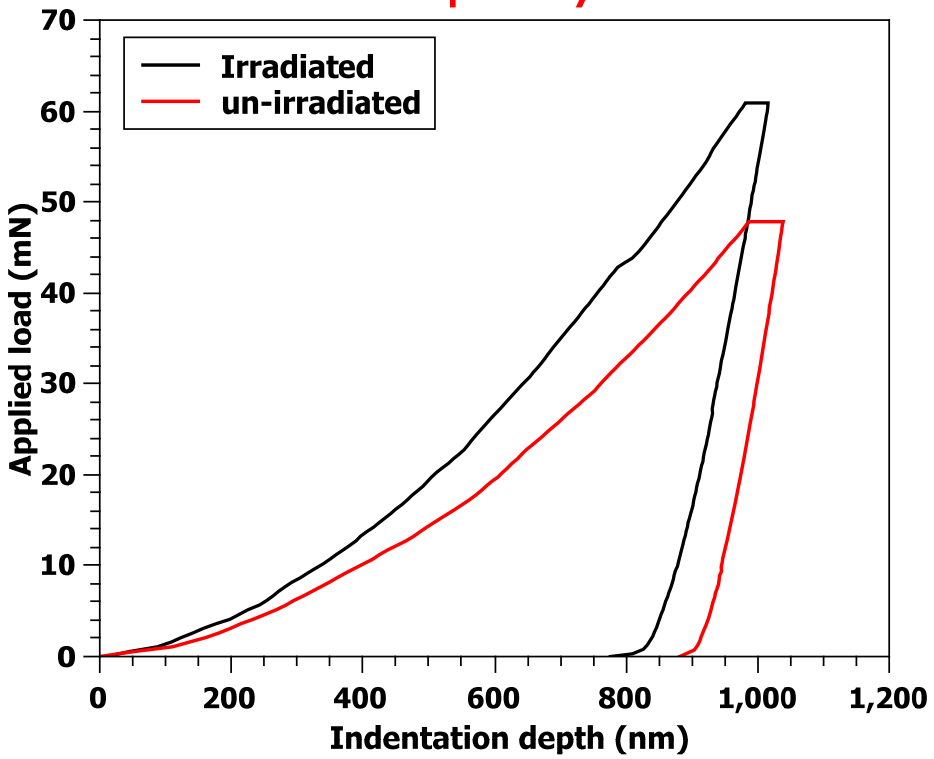
Parameters for nano-indentation:

1μm depth control with constant loading rate of 10mN/s with a Berkovich tip.

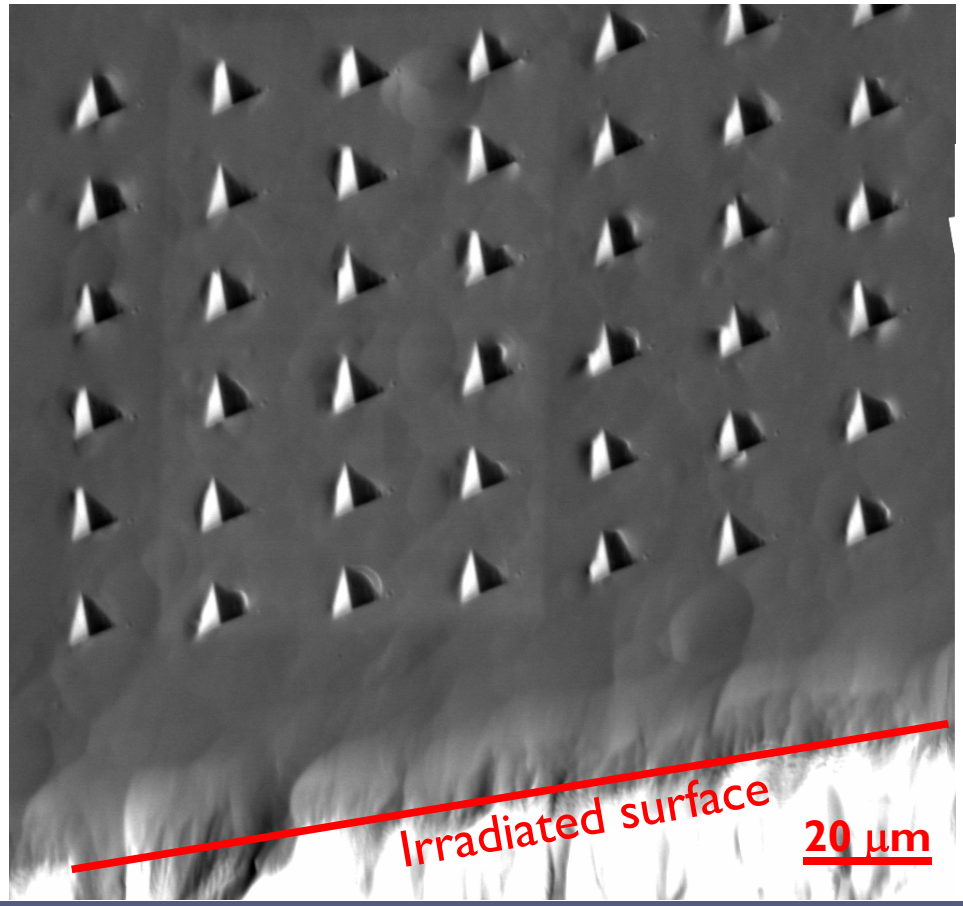
Testing surface:

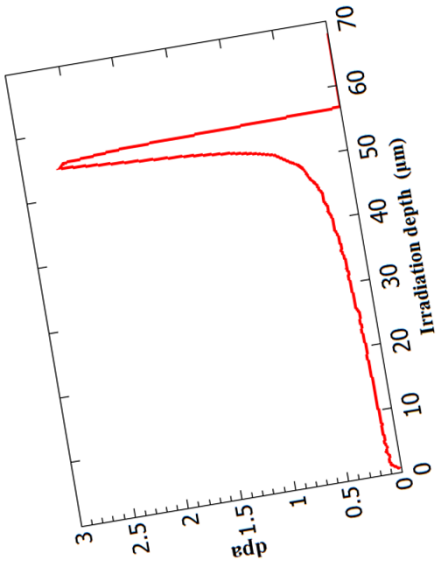
irradiated side and cross section side

Load-depth hysteresis

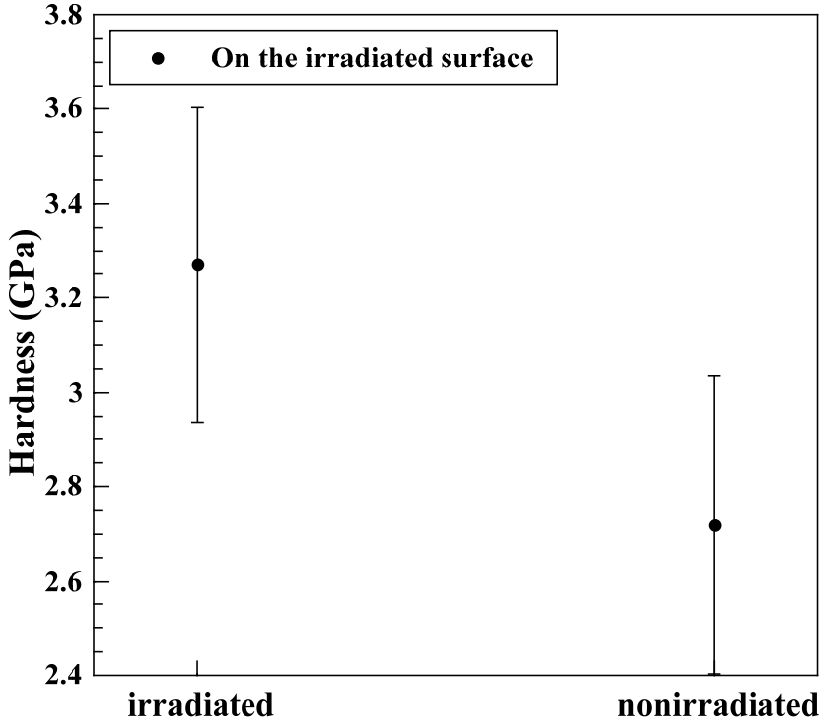


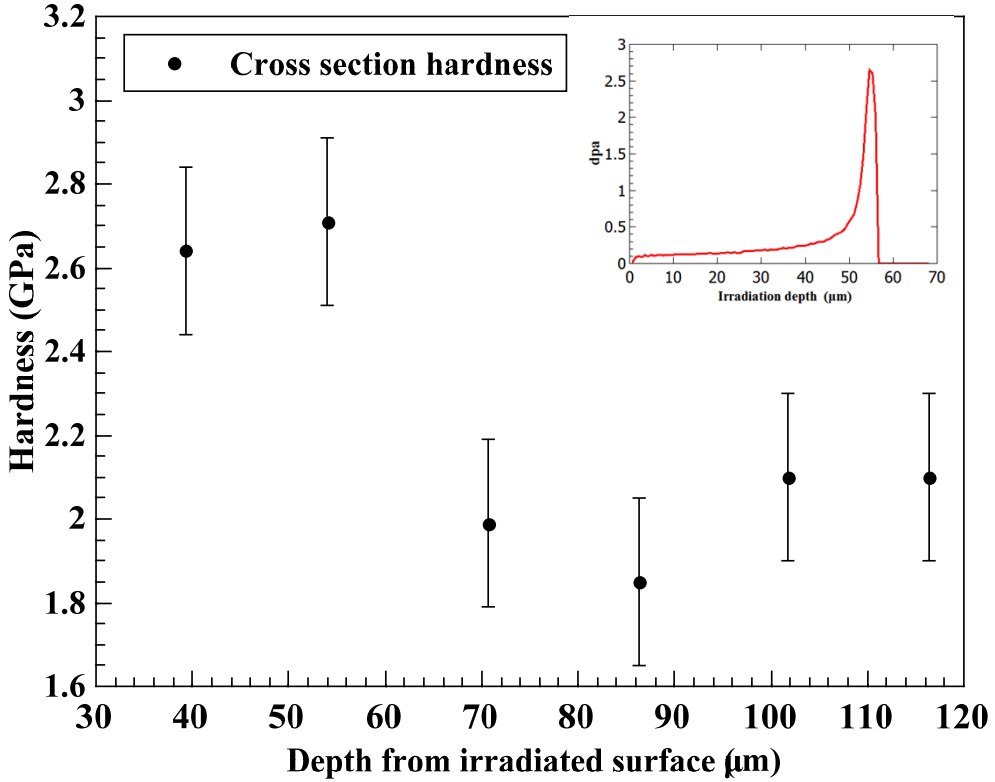
Nano-indentation hardness test



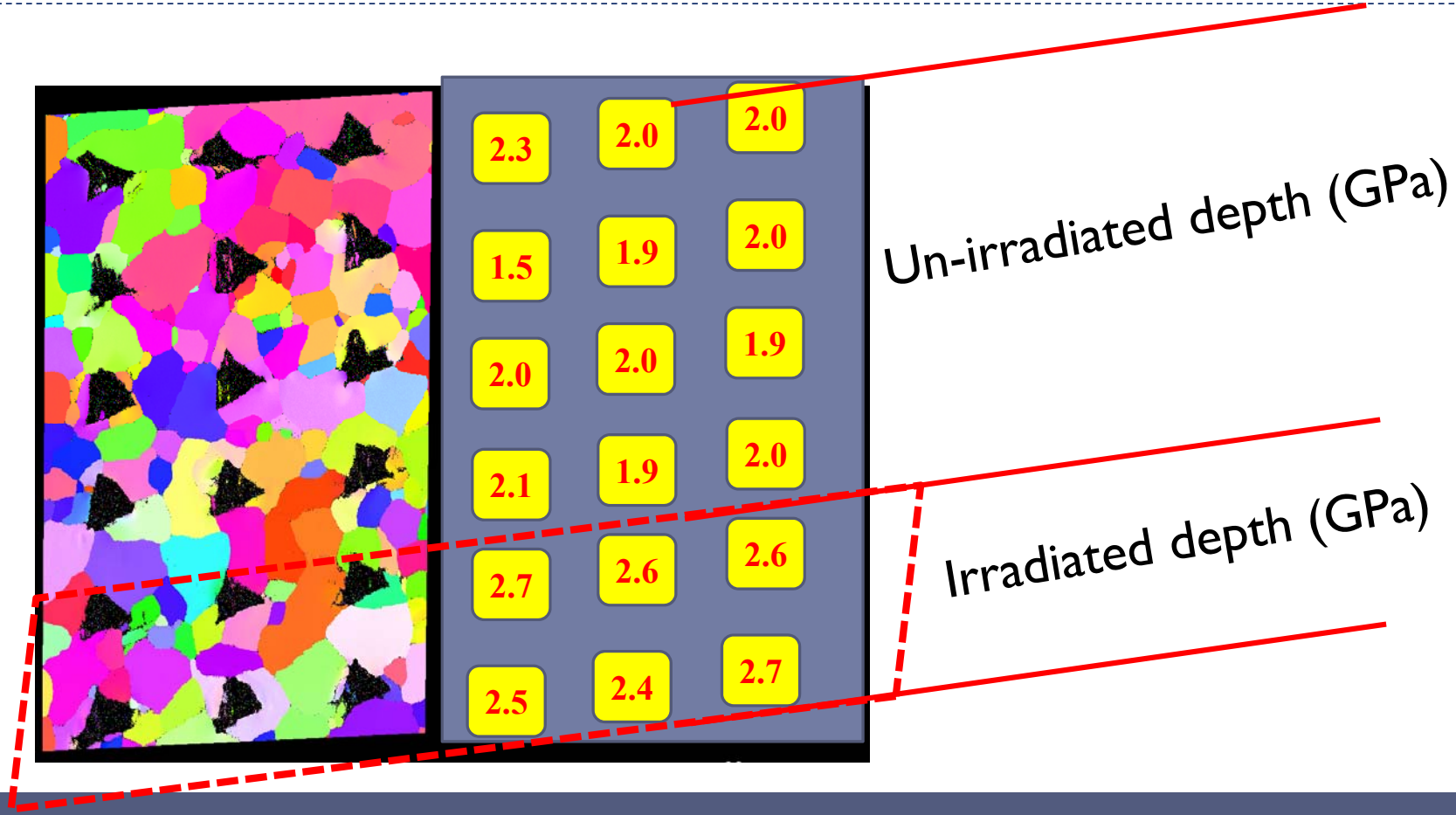


Nano-indentation hardness test

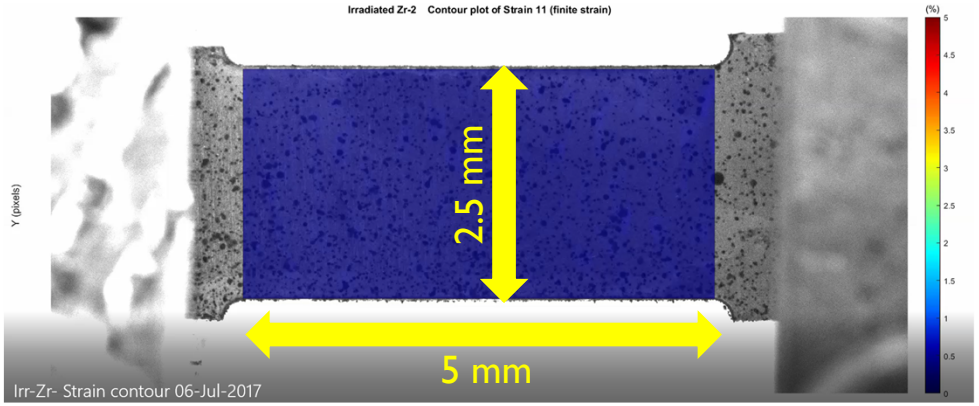




Nano-indentation hardness test

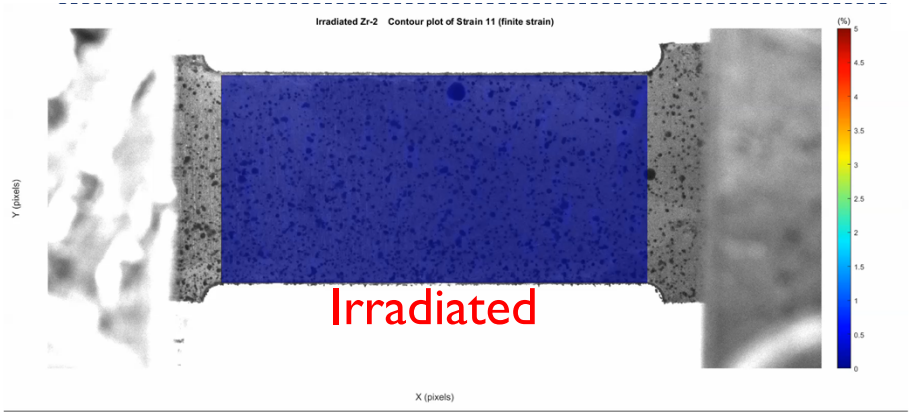


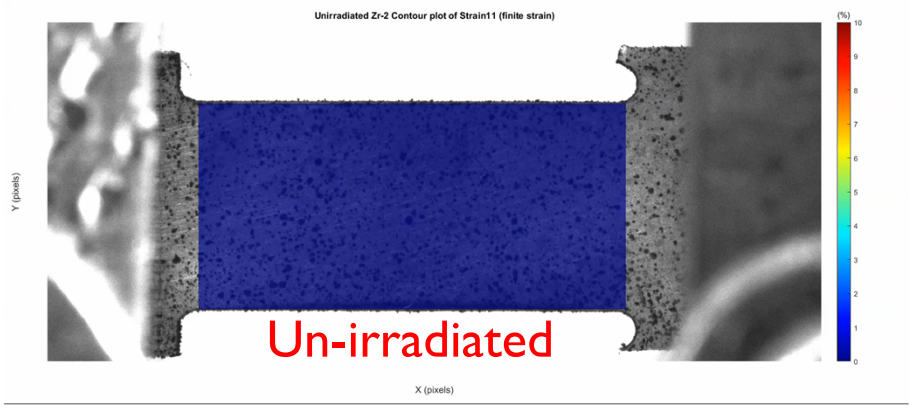
Effect of irradiation on the yield strength



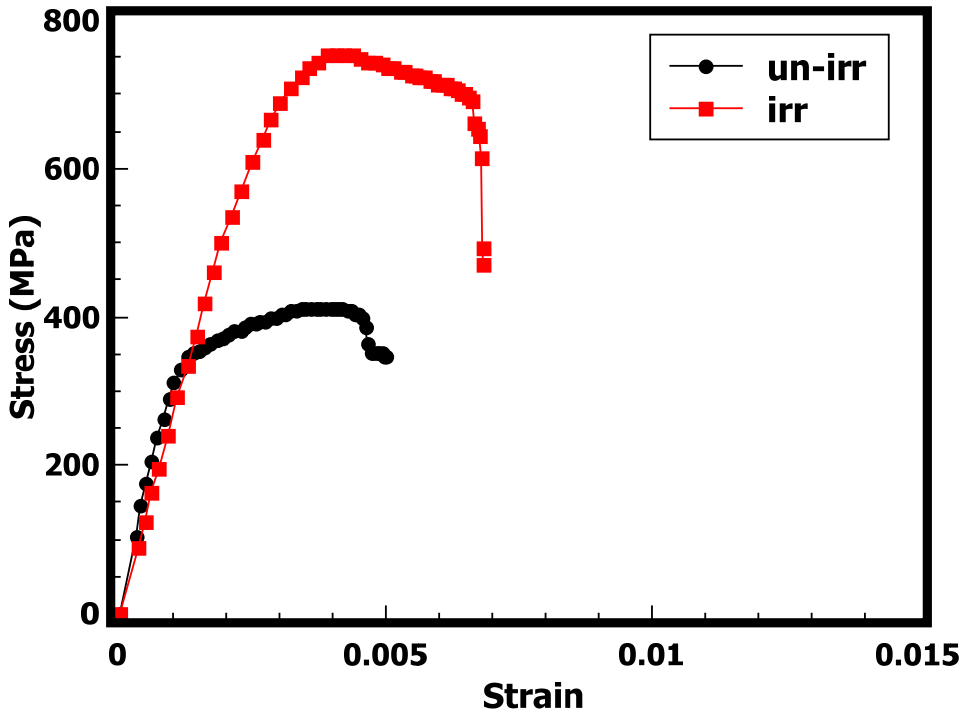
Foil thickness was reduced from the un-irradiated side down to 60 μm, and one reference sample with the same geometry was prepared from the un-irradiated area of the same sample.

Tensile stress-strain obtained by DIC

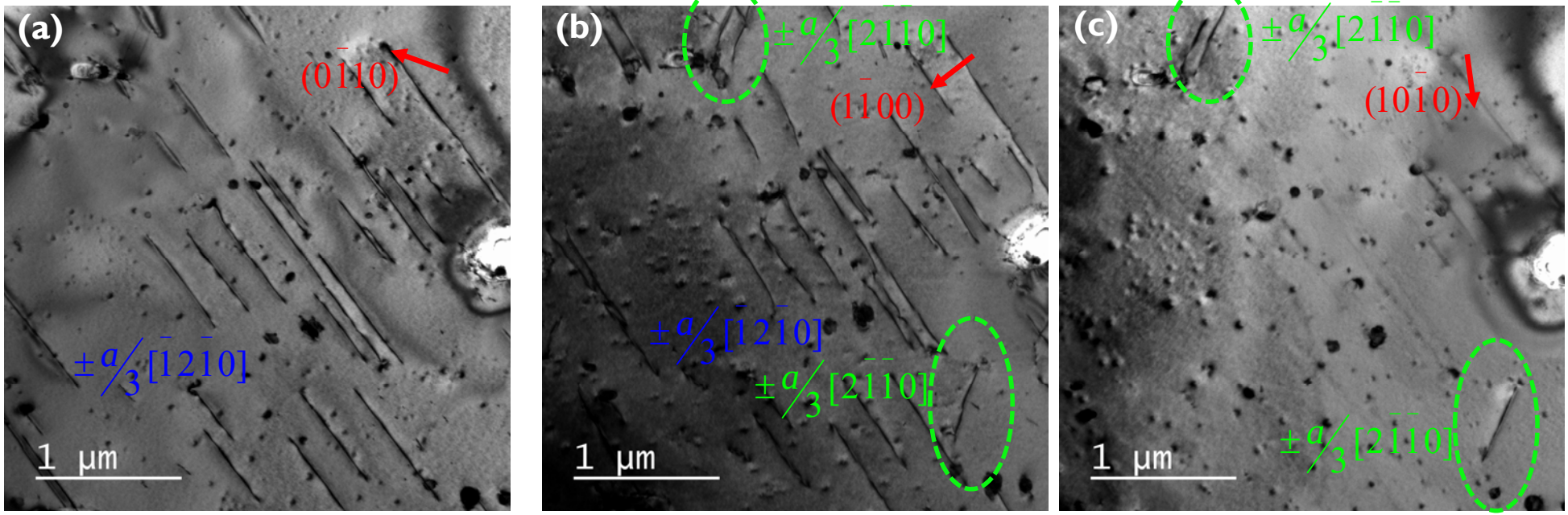




$\sigma_{0.2}$: Irradiated: 733 MPa
: Un-irradiated: 411 MPa

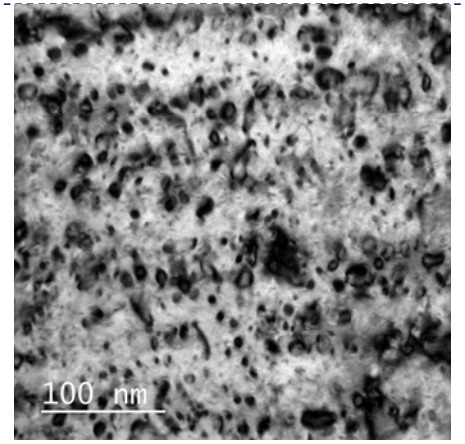


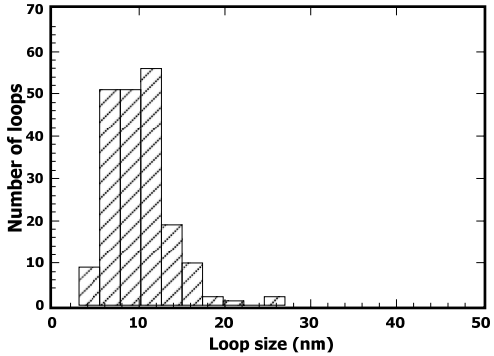
Deformed microstructure (un-irradiated)

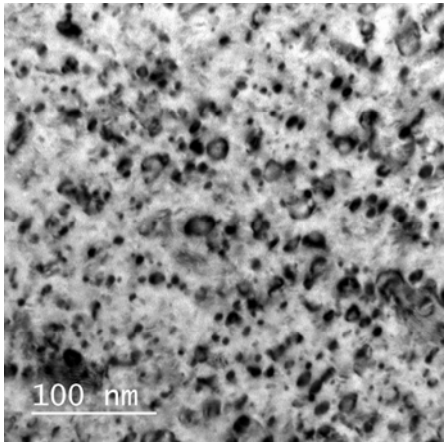


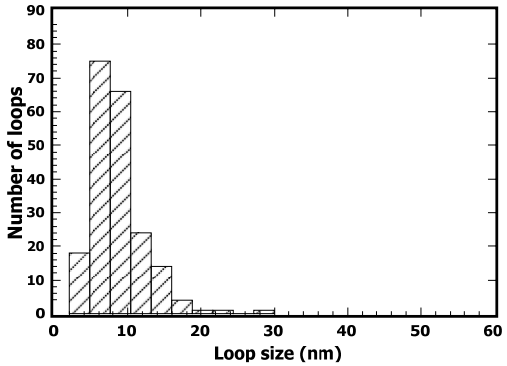
Predominantly prismatic screw <a> dislocations operating to accommodate plastic deformation

Deformed microstructure (irradiated-gauge length)





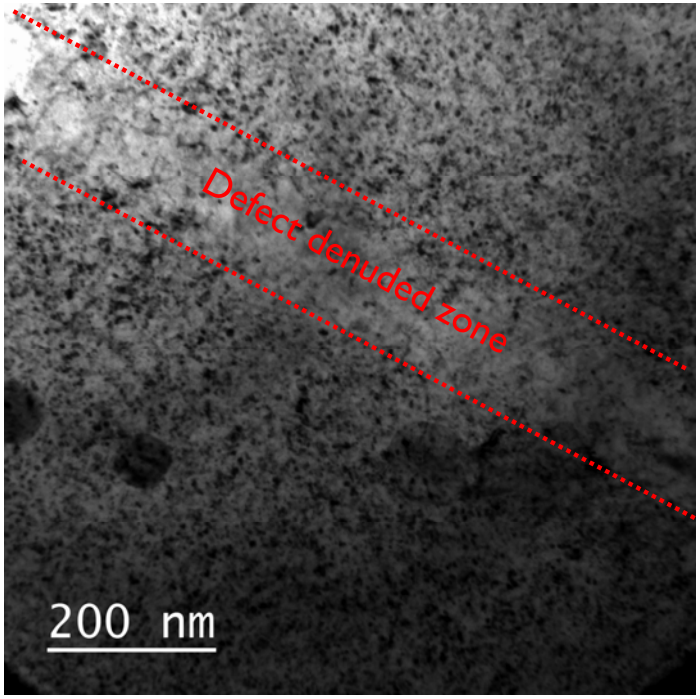


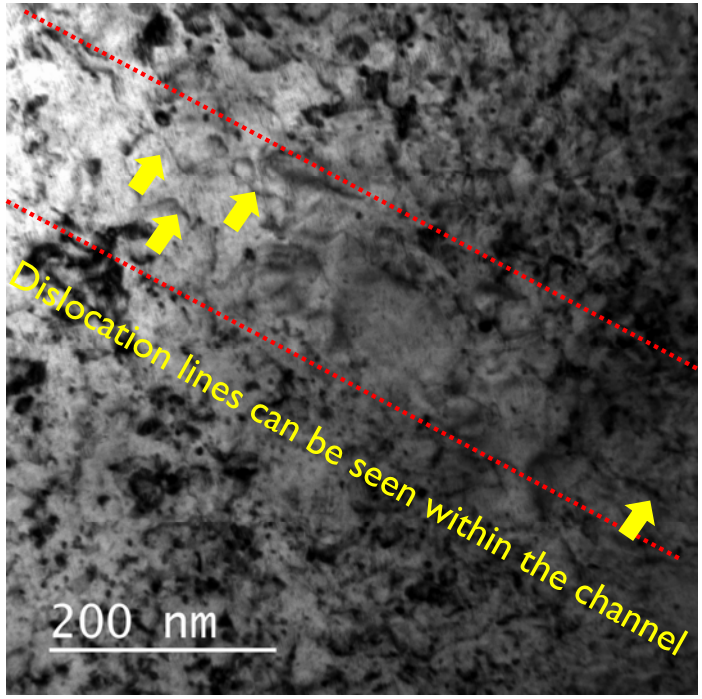


Loop size:
no significant change

Loop distribution:
The patterning along basal plane trace became indistinguishable.

Deformed microstructure (irradiated-shoulder)





Prismatic channels were found in grains that have underwent larger plastic strains over the shoulder area.

Conclusions

- Significant amount of <a> dislocation loops has been generated by 3MeV proton beam at 180°C to 0.11dpa in an Zircaloy-2 alloy.
- The irradiation induced microstructural change was found to be very similar to that of the neutron irradiated alloy.
- Both nano-indentation hardness measurement and thin foil tensile test show significant hardening that has been induced by the dislocation loops.
- Irradiation has great impact on the deformation mechanism of the alloy, which changes from easy dislocation glide to more difficult dislocation channeling.

Thank you for your attention!

Acknowledgements

Tom Feuerstake, Curtis McDonald, and Kazi Ahmmed from RMTL for conducting the irradiation;
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