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Radiation Effects in ZrN

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Introduction

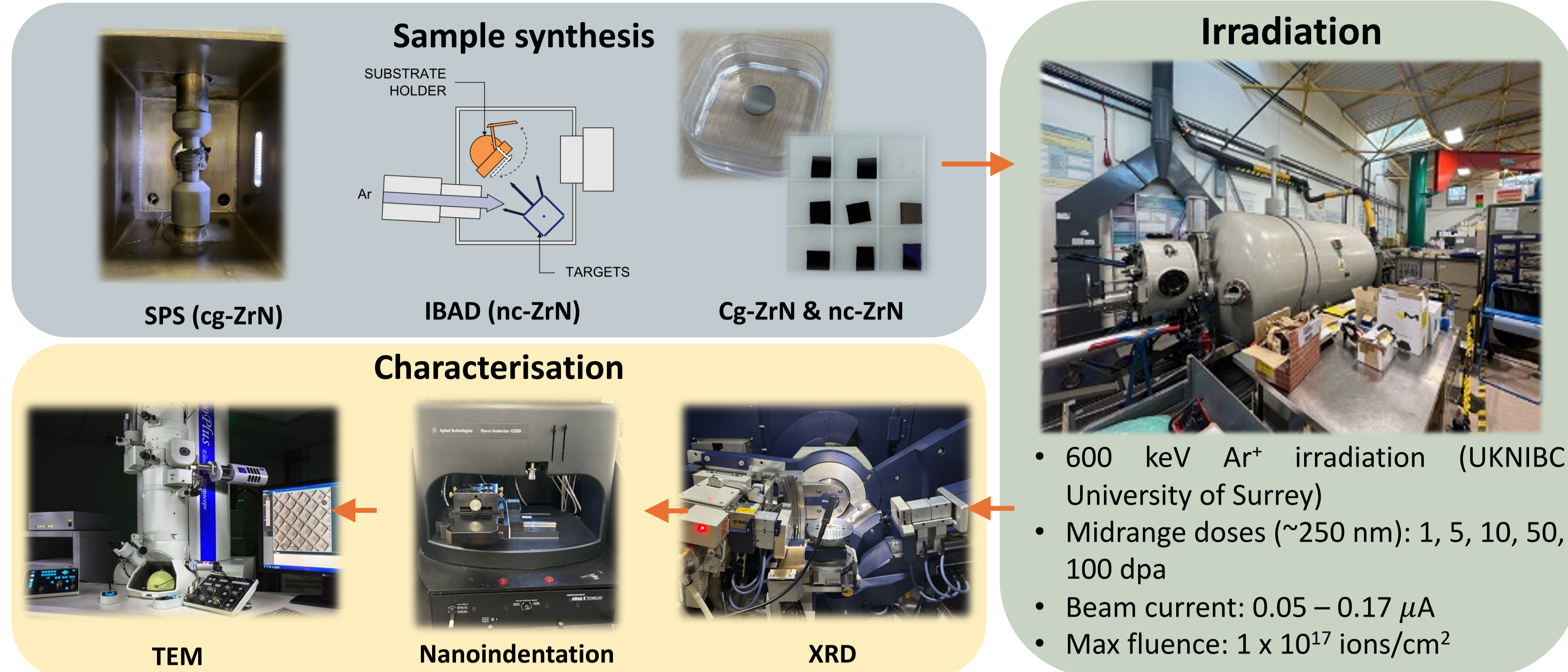
This work explores the effects of **displacive radiation damage** in **ZrN**, using ion beam irradiations.

- Next generation nuclear power reactors will use novel fuel types; promising improved **efficiency** and **safety**.
- UN** is an advanced fuel concept possessing a high fissile U density, thermal conductivity and melting temperature.
- ZrN** is the **surrogate system** of **UN** possessing similar chemical properties and identical structure.
- As fuel ages, radiation-induced damage accumulates, leading to **undesirable material property changes**.
- A better understanding of **UN material behaviour** and related **mechanistic processes** is needed if it is to be employed in next generation reactors.

Experimental objectives:

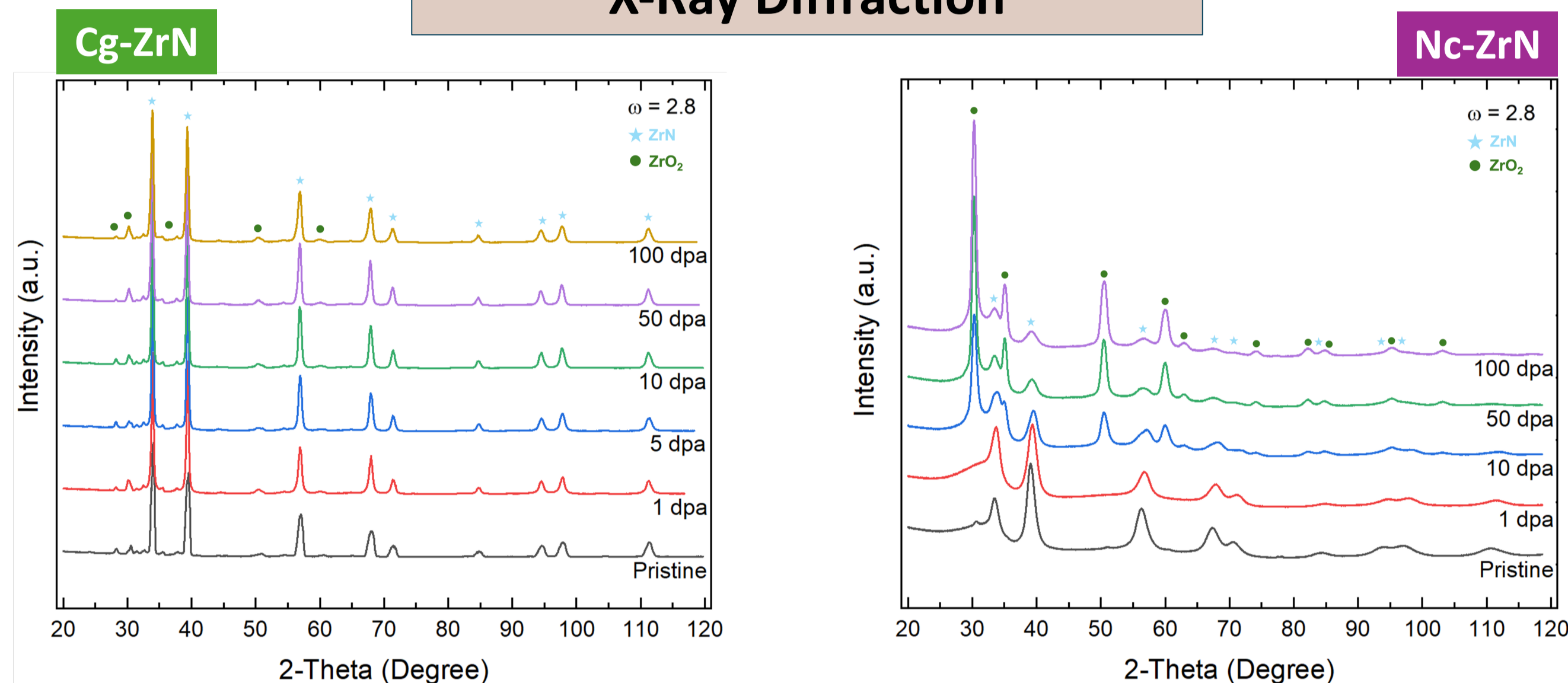
- Investigate the mechanistic role of damage induced by the primary knock-on atom (PKA) of neutrons.
- Explore the effect of coarse-grained (cg) and nanocrystalline (nc) grain size on radiation tolerance
- Correlate microstructural modifications to changes in bulk material properties.

Methods

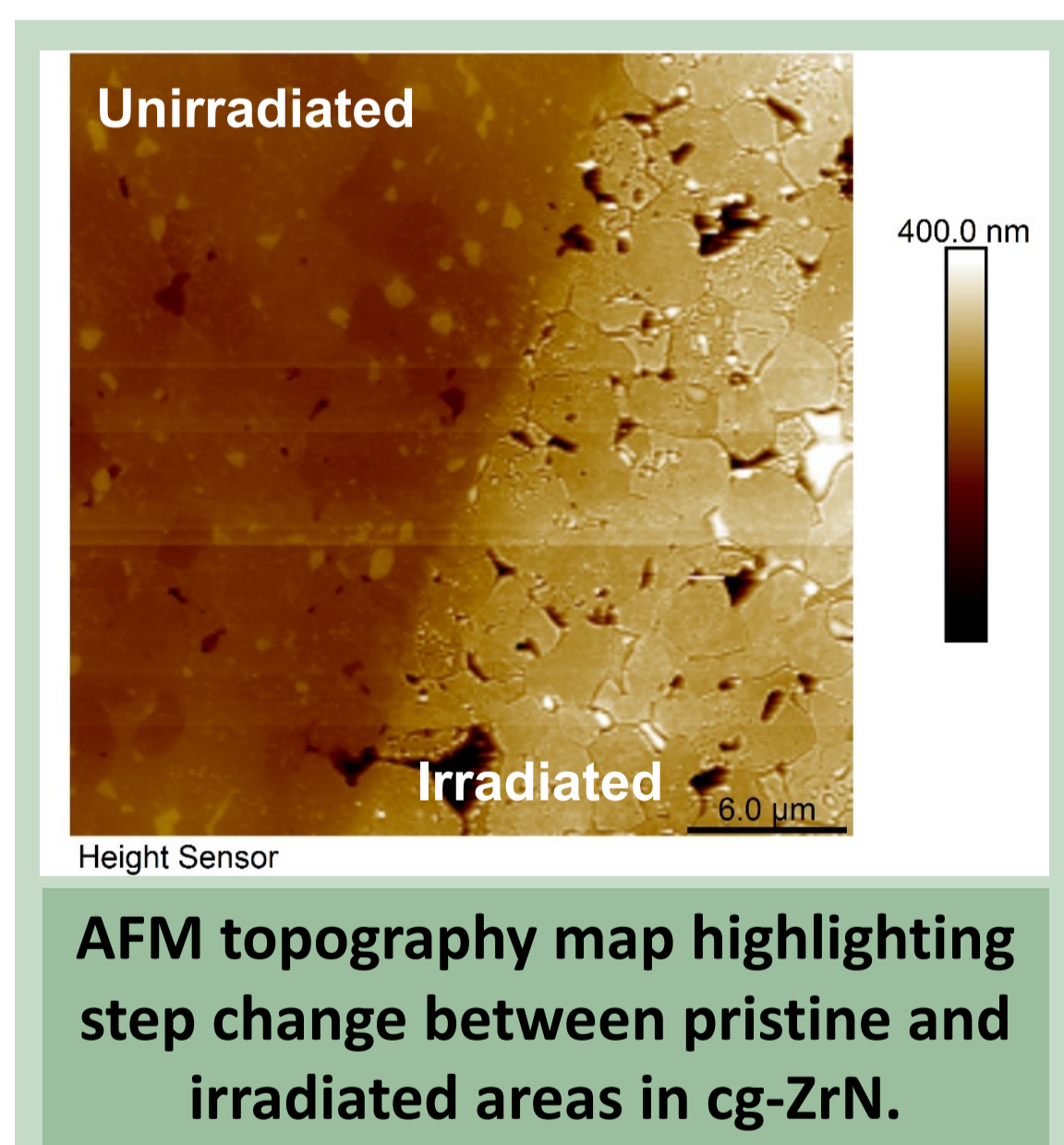
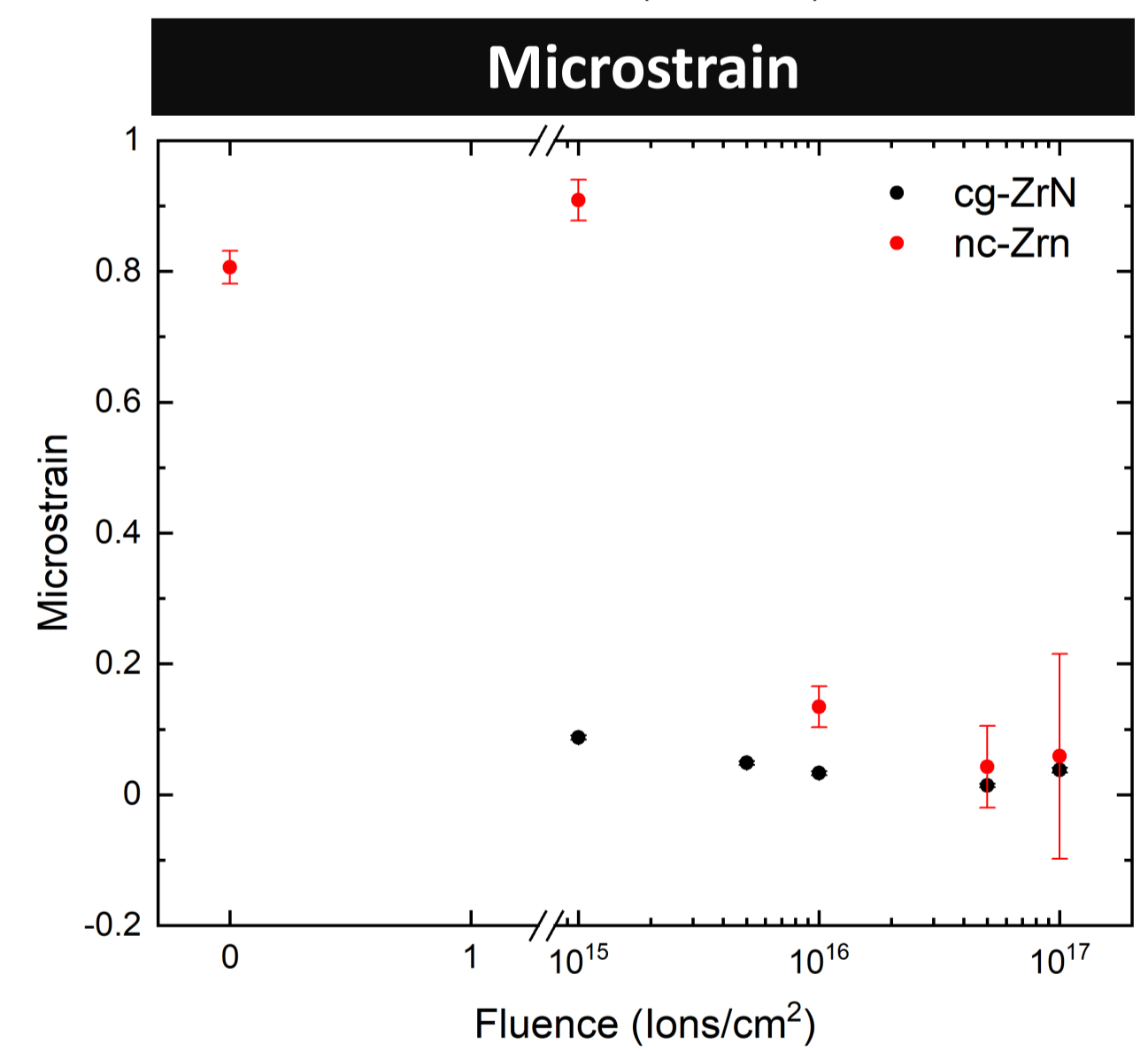
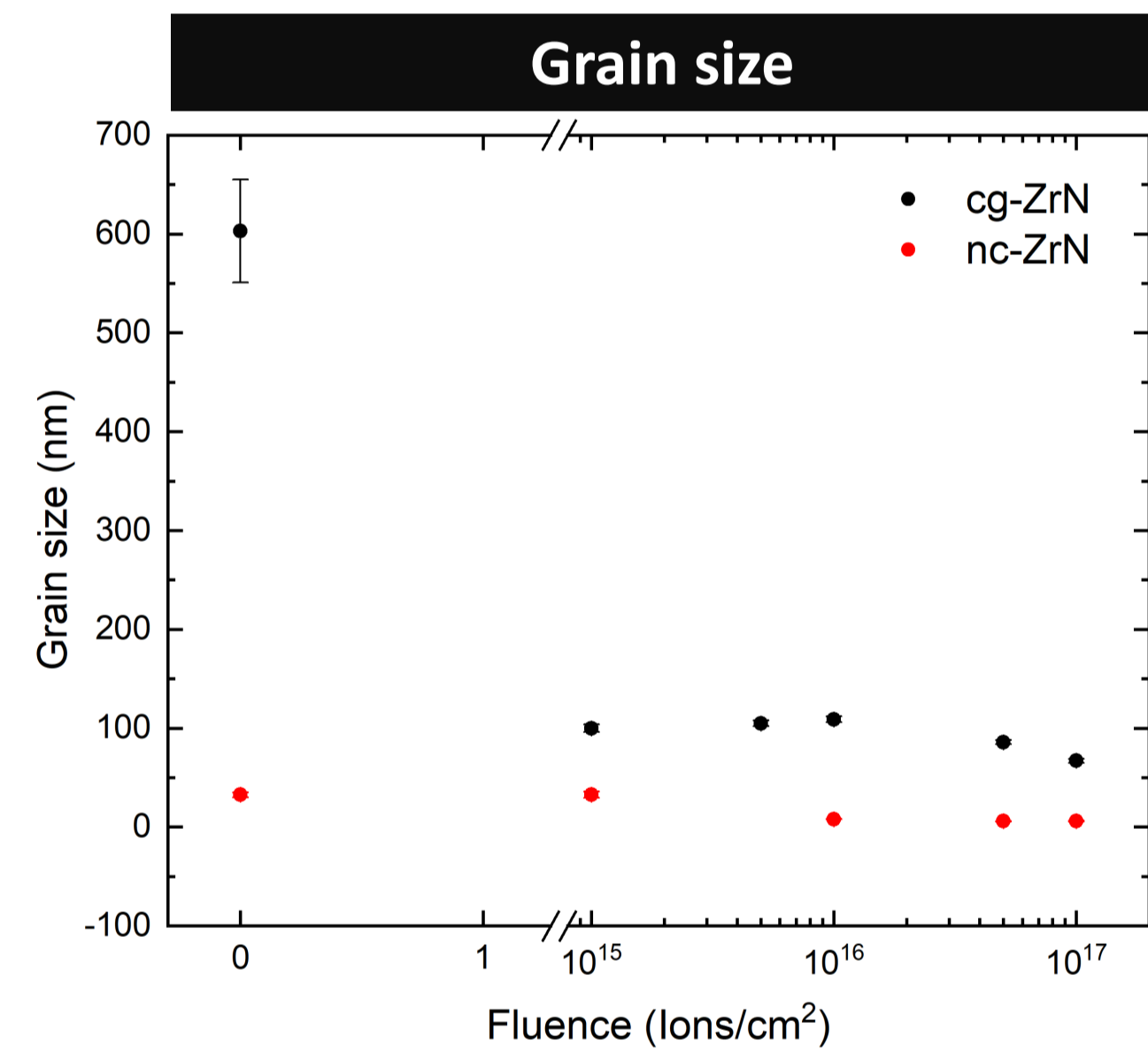
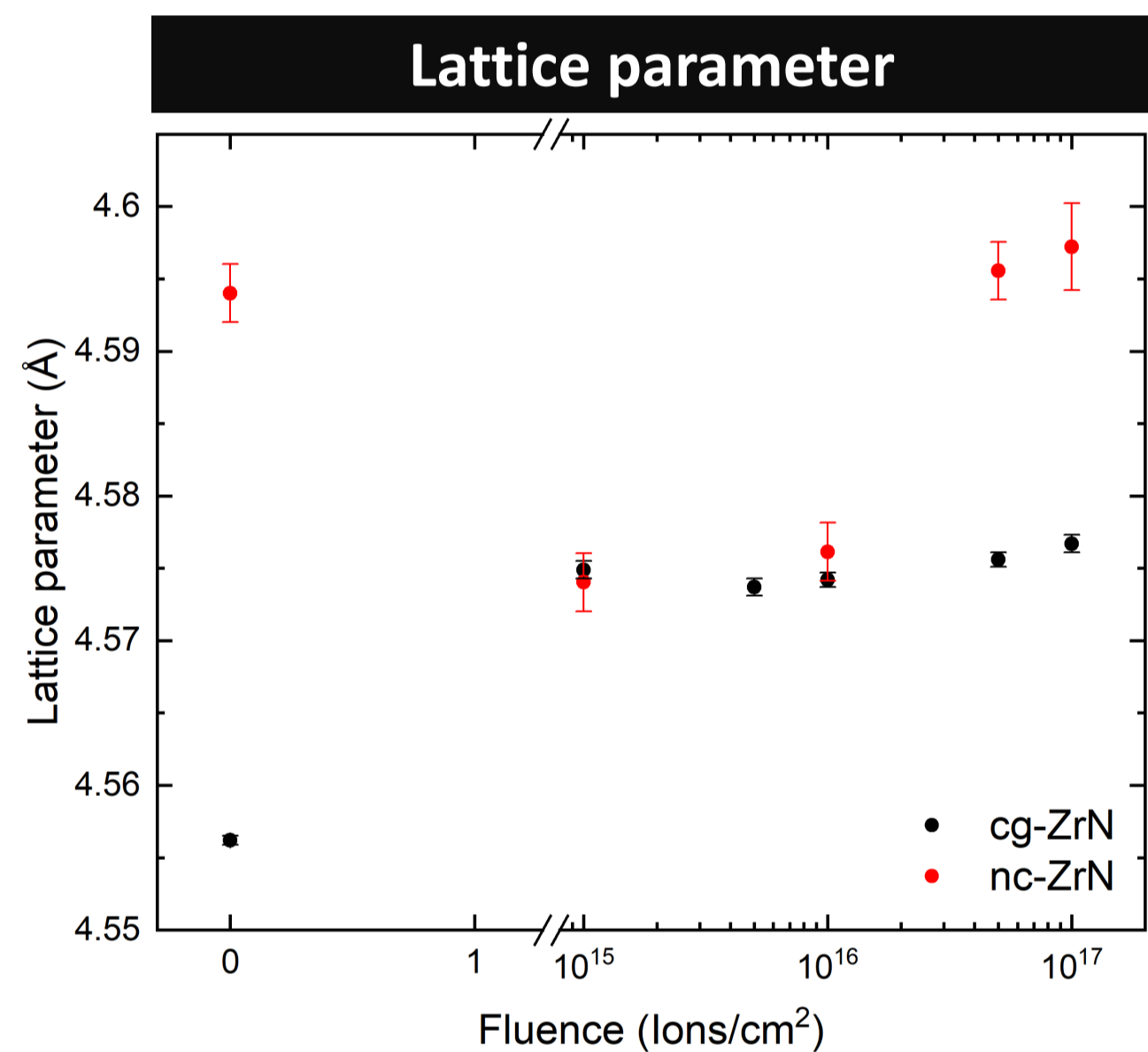


Results

X-Ray Diffraction

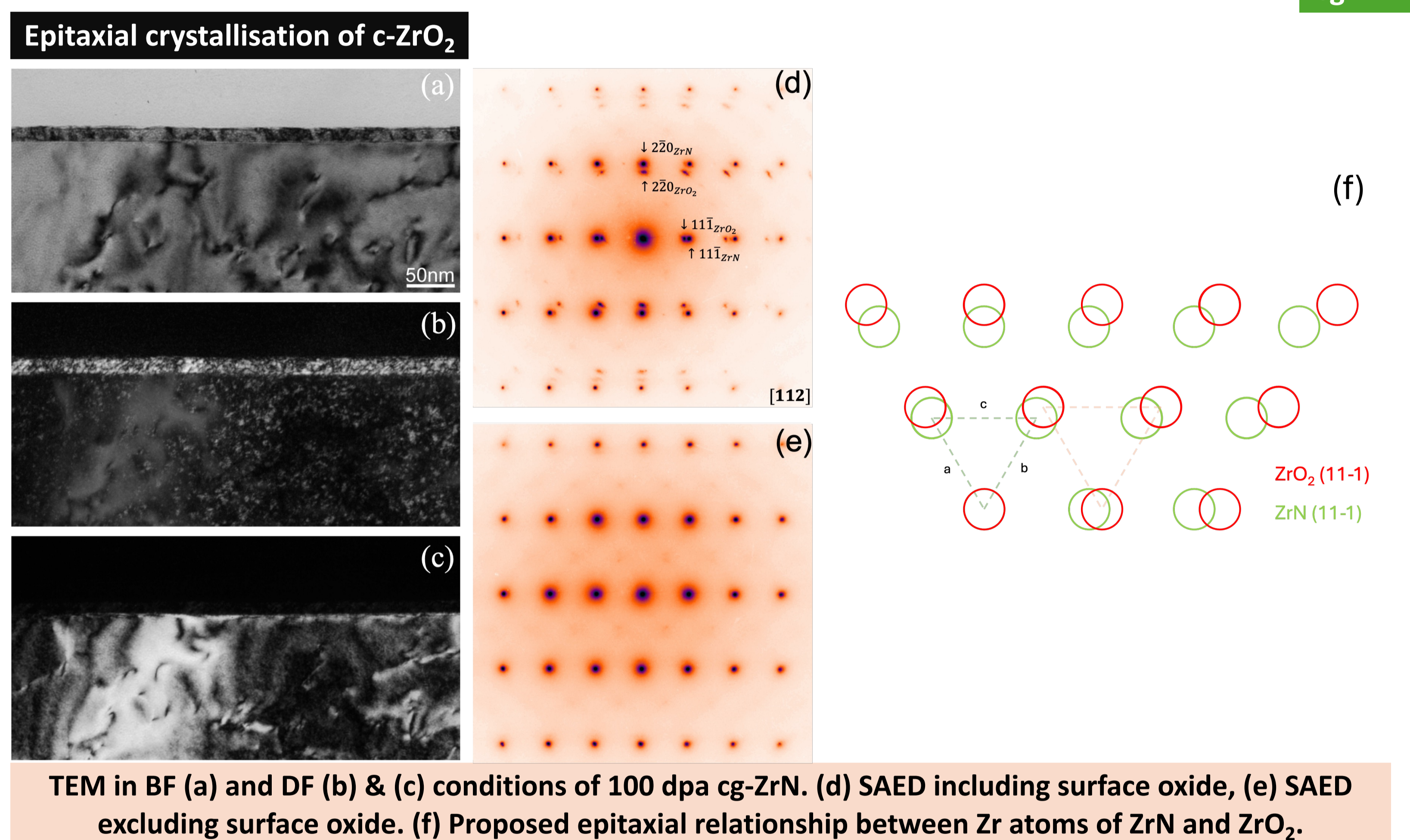


GIXRD of 600 keV Ar irradiated cg-ZrN (left) and nc-ZrN (right).

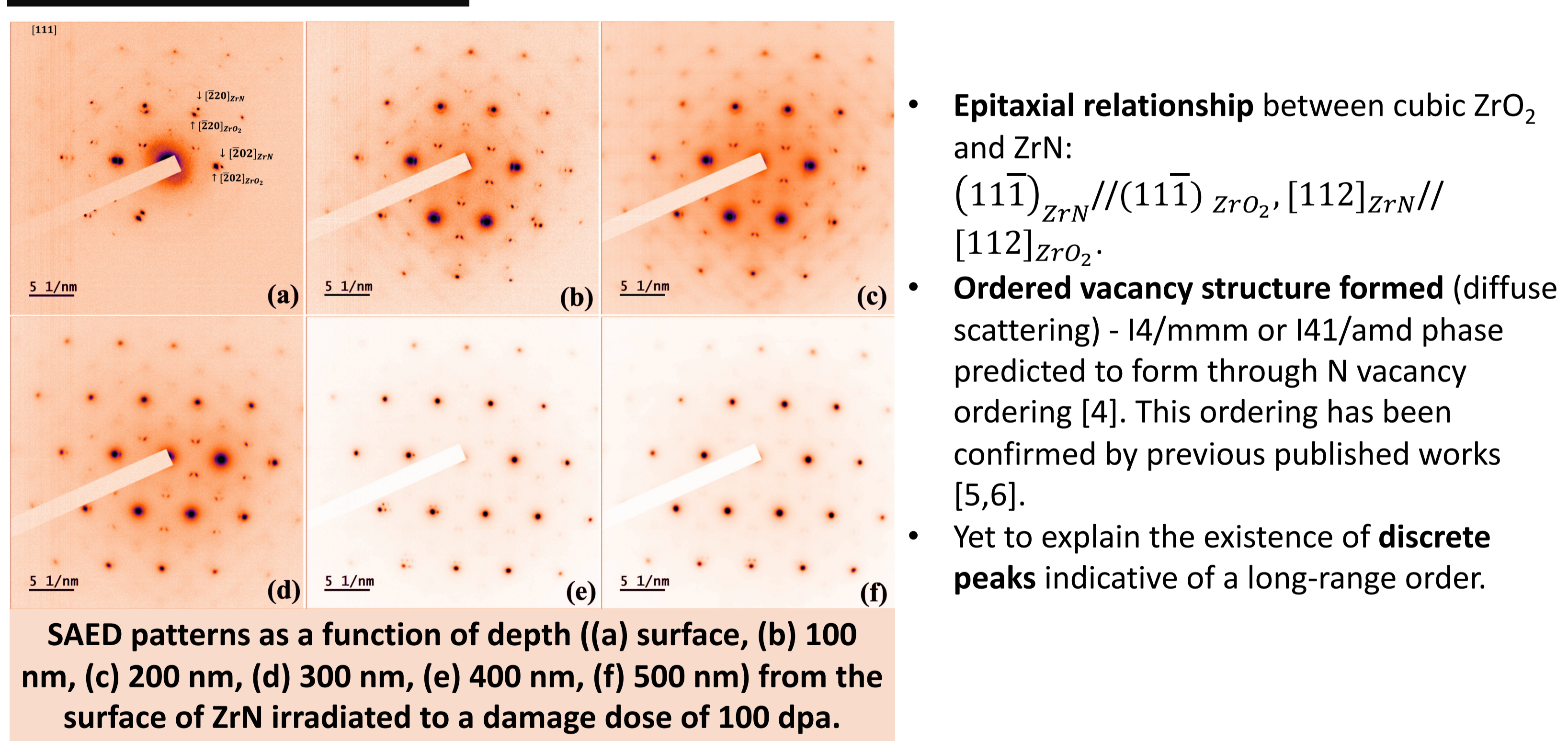


- Lattice parameter increase** observed in both ZrN systems.
- Grain size decrease** or 'polygonisation' [1] observed in both ZrN systems.
- ZrO₂ crystallises** at a damage threshold between 1 and 10 dpa in nc-ZrN.

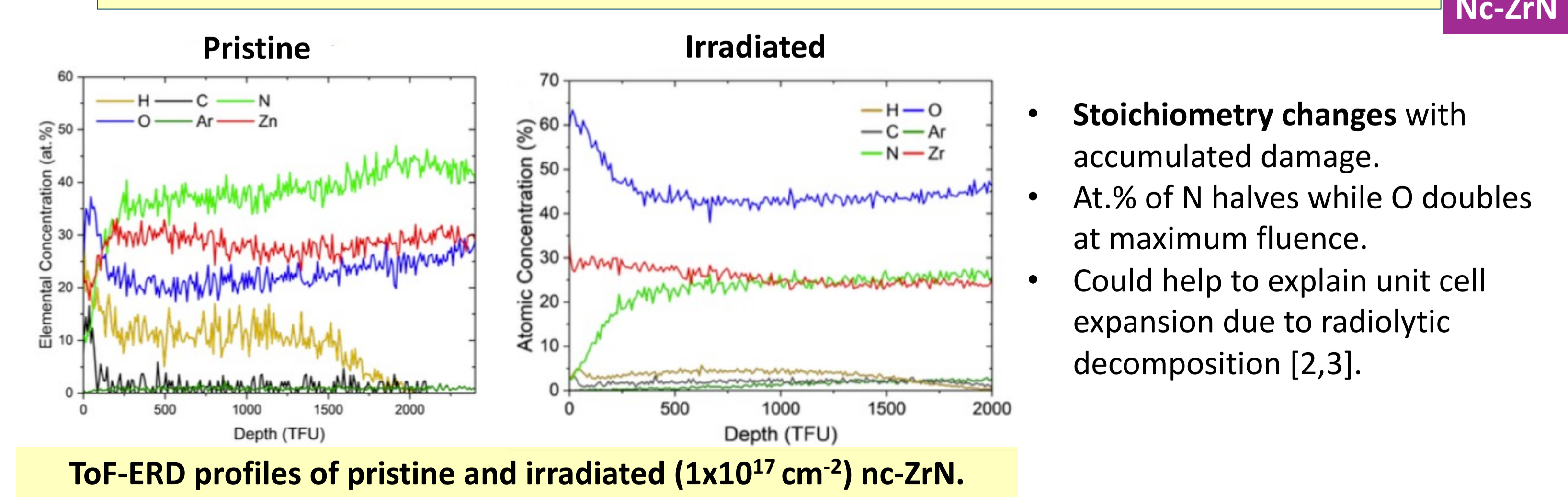
Transmission Electron Microscopy



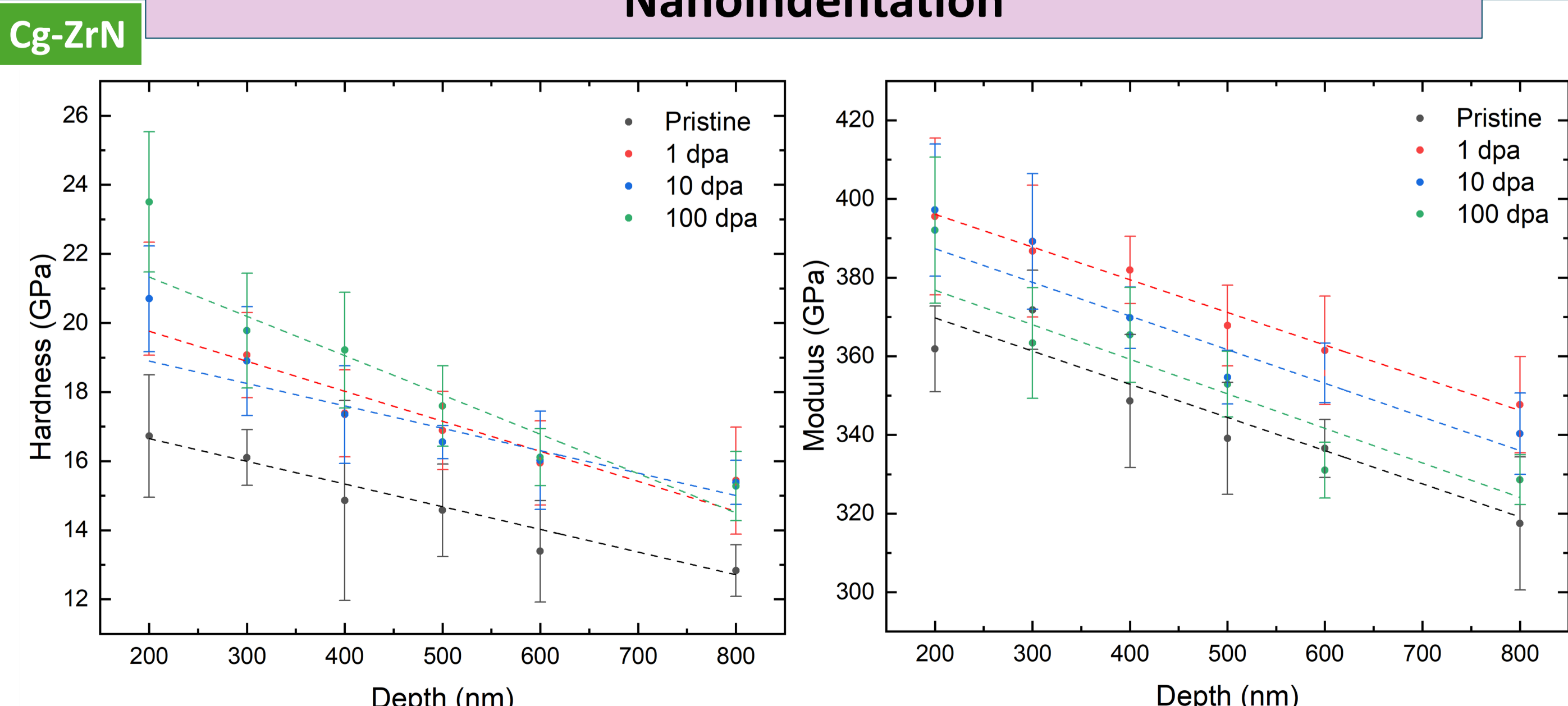
Correlated disorder in cg-ZrN



ToF – Elastic Recoil Detection



Nanoindentation



Hardness (left) and modulus (right) evolution of cg-ZrN vs. depth probed. Linear fits in corresponding colours have been applied to help guide the eye

Conclusions

- Cg-ZrN** is highly tolerant to displacive interactions experienced via low energy ions and neutrons.
- Nc-ZrN** appears to be more susceptible to radiation-induced changes – stoichiometry & oxidation
- Both ZrN systems display **grain size reduction** and **unit cell expansion** as damage accumulates.
- Evidence of **Short- and long-range ordering** observed in irradiated **cg-ZrN** system.
- Nc-ZrN** displays a damage threshold at which **c-ZrO₂** phase begins to crystallise.
- Mechanical properties** are not detrimentally affected by displacive ion interactions.

Ongoing Work

- TEM characterisation of 600 keV Ar irradiated nc-ZrN
- Influences of electronic to nuclear stopping ratios on radiation effects in cg-ZrN, nc-ZrN and UN. Currently analysing: 92 MeV Xe, 30 MeV Au, 9 MeV Si, 7 MeV Au, 1.5 MeV Si.

References

- [1] Matzke, H. & Kinoshita, M. (1997) *Journal of Nuclear Materials*, 247, pp. 108-115.
 [2] Terricabras, A. J. et al. (2022) *Journal of Nuclear Materials*, 563, 153643.
 [3] Toth, L. E. (1971) *Transition Metal Carbides and Nitrides*, Academic Press, New York.