SAND2021-8827C

In-situ TEM Irradiation Induced Amorphization of $Ge_2Sb_2Te_5$

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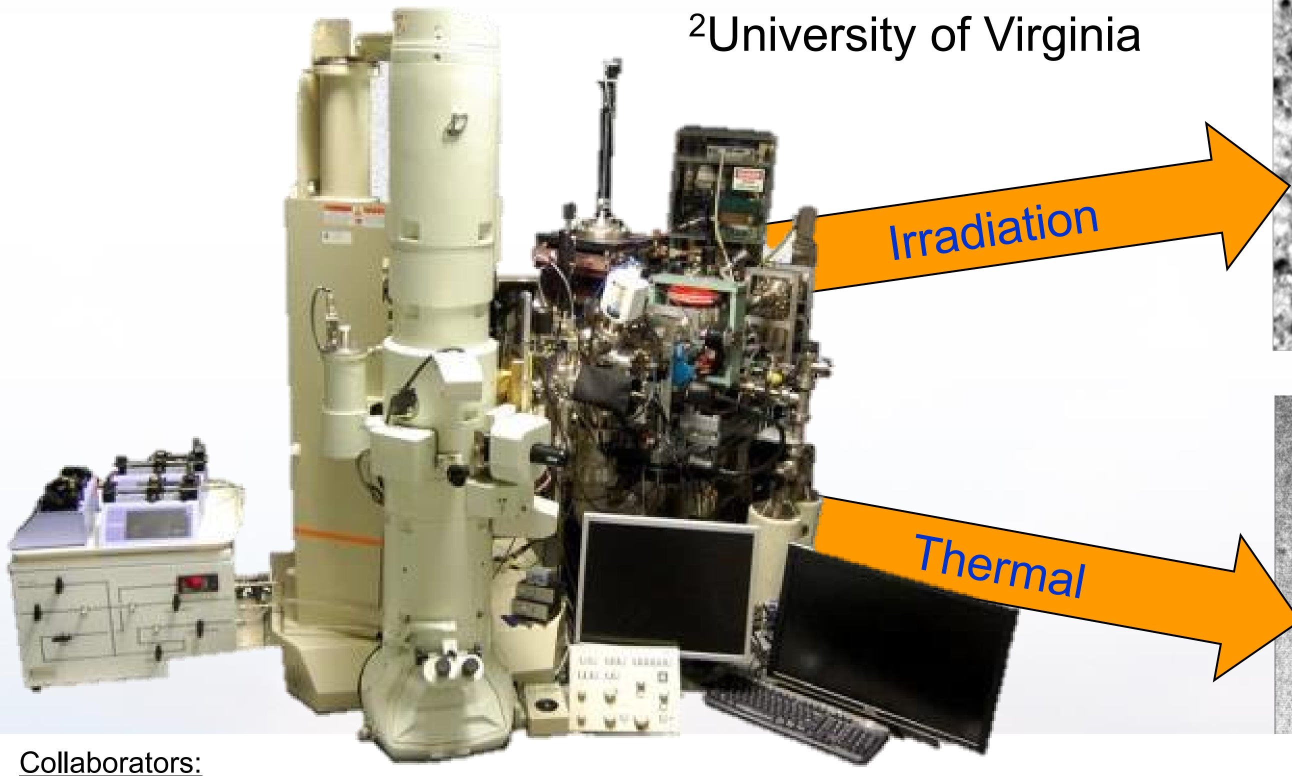
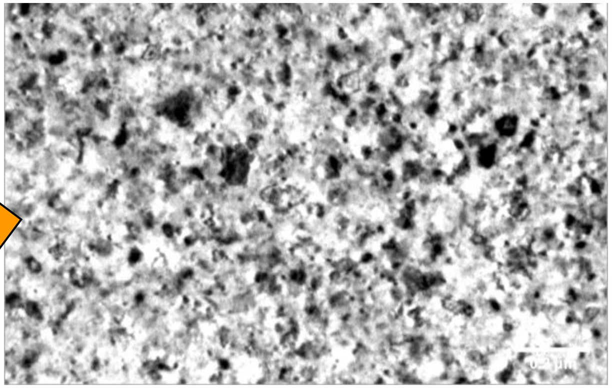
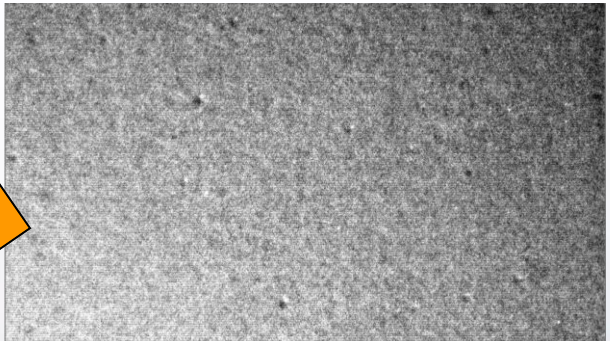
[2]University of Virginia







Collaborators:

- D.L. Buller, D.C. Bufford, S.H. Pratt, T.J. Boyle, B.A. Hernandez-Sanchez, S.J. Blair, B. Muntifering, C. Chisholm , P. Hosemann, A. Minor, J. A. Hinks, F. Hibberd, A. Ilinov, D. C. Bufford, F. Djurabekova, G. Greaves, A. Kuronen, S. E. Donnelly, K. Nordlund, F. Abdeljawad, S.M. Foiles, J. Qu, C. Taylor, J. Sugar, P. Price, C.M. Barr, D. Adams, M. Abere, L. Treadwell, A. Cook, A. Monterrosa, IDES Inc, J. Sharon, B. L. Boyce, C. Chisholm, H. Bei, E.P. George, W. Mook, Hysitron Inc., G.S. Jawaharram, S. Dillon, R.S. Averback, N. Heckman, J. Carroll, S. Briggs, E. Carnes, J. Brinker, D. Sassaki, T. Nenoff, B.G. Clark, P.J. Cappillino, B.W. Jacobs, M.A. Hekmaty, D.B. Robinson, L.R. Parent, I. Arslan. K. Jungjohann, & Protochips, Inc.

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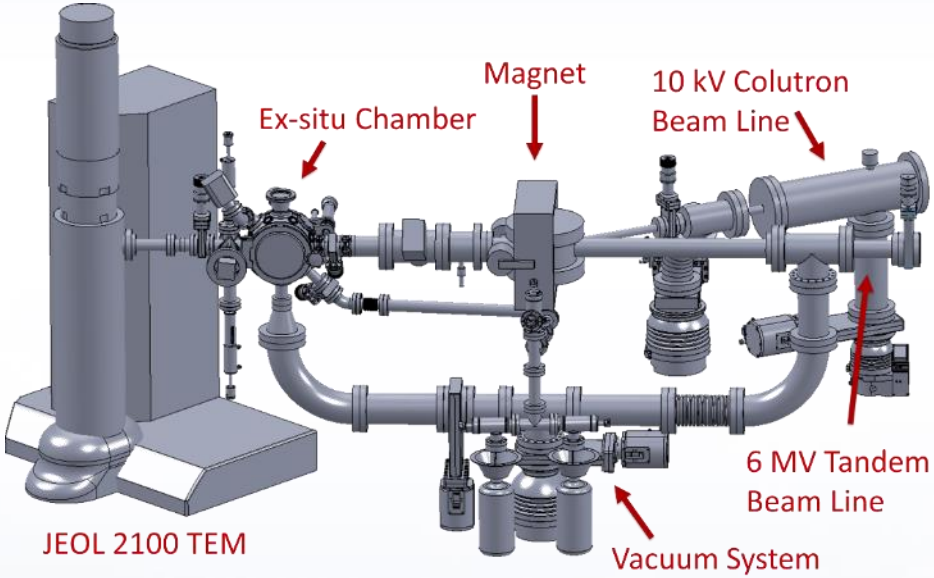
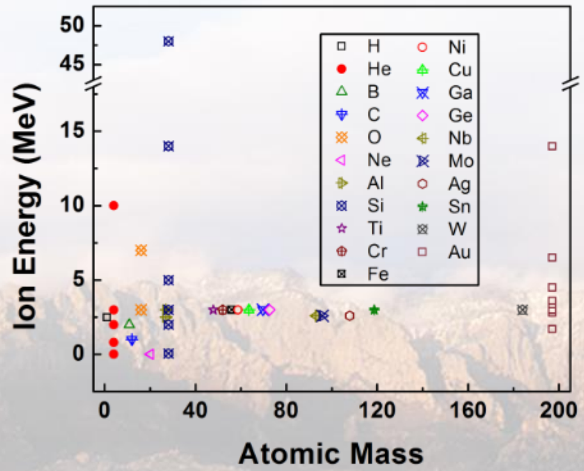
Sandia's Concurrent *In situ* Ion Irradiation TEM Facility

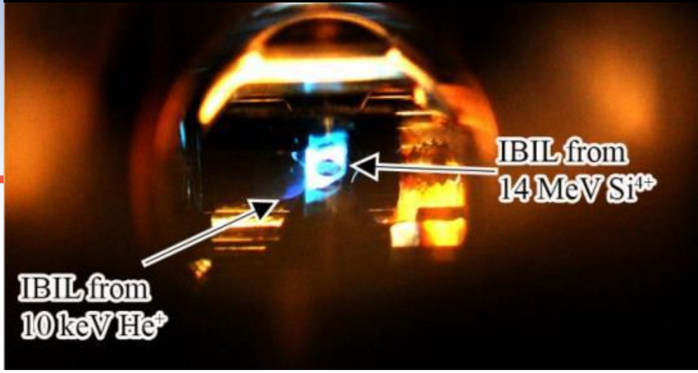
Collaborator: D.L. Buller

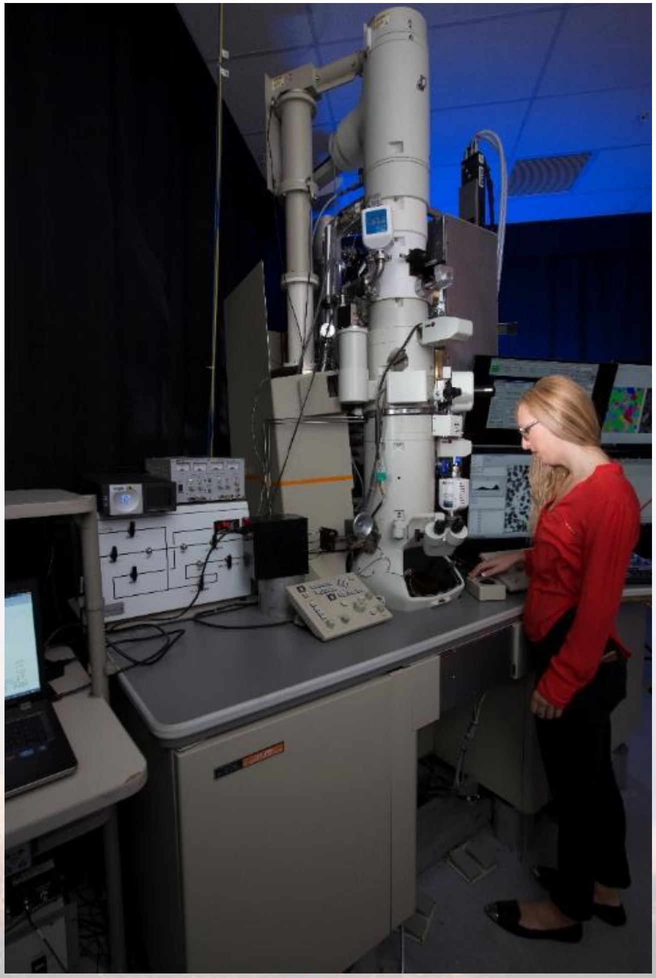
10 kV Colutron - 200 kV TEM - 6 MV Tandem





IBIL from a quartz stage inside the TEM

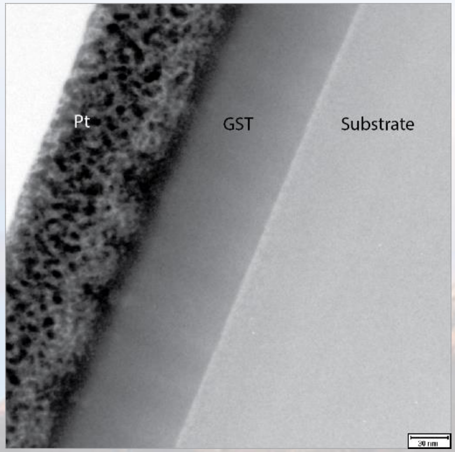


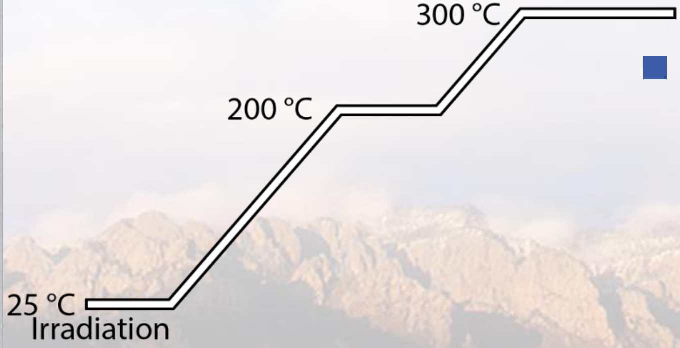


Sample Preparation and Experimental Conditions

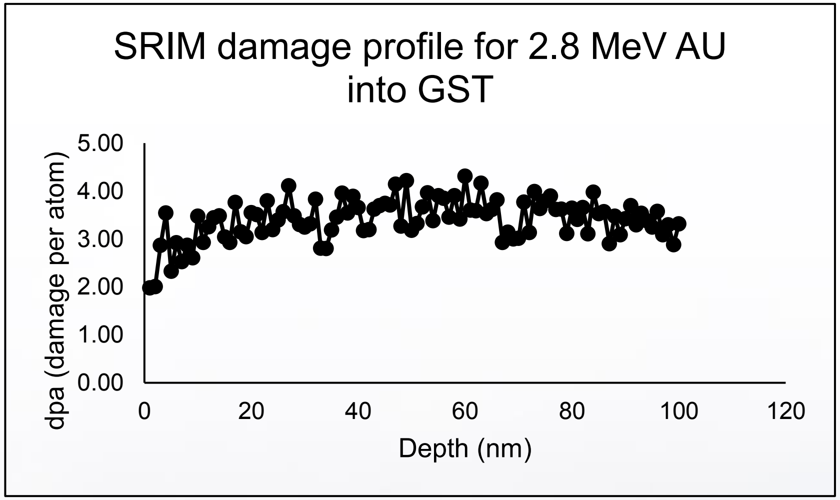
- **90 nm-thick GST with 0 % C - 20 % C**
- **Plan View:**
  - Anneal (5 ˚C/min)
  - RT irradiation (4dpa)
    - Anneal (5 ˚C/min)
  - 100 ˚C hold & irradiation (4dpa)

- **Cross section FIB lift-outs:**
  - RT Irradiation
    - 200 C & 300 C Hold





- **Irradiation Conditions**
  - 2.8 MeV Au^{4+}
  - Up to 4 dpa



- **Data Analysis**
  - SRIM simulation data is used to calculate damage level (DPA) from this fluence
  - Manual rain size analysis done

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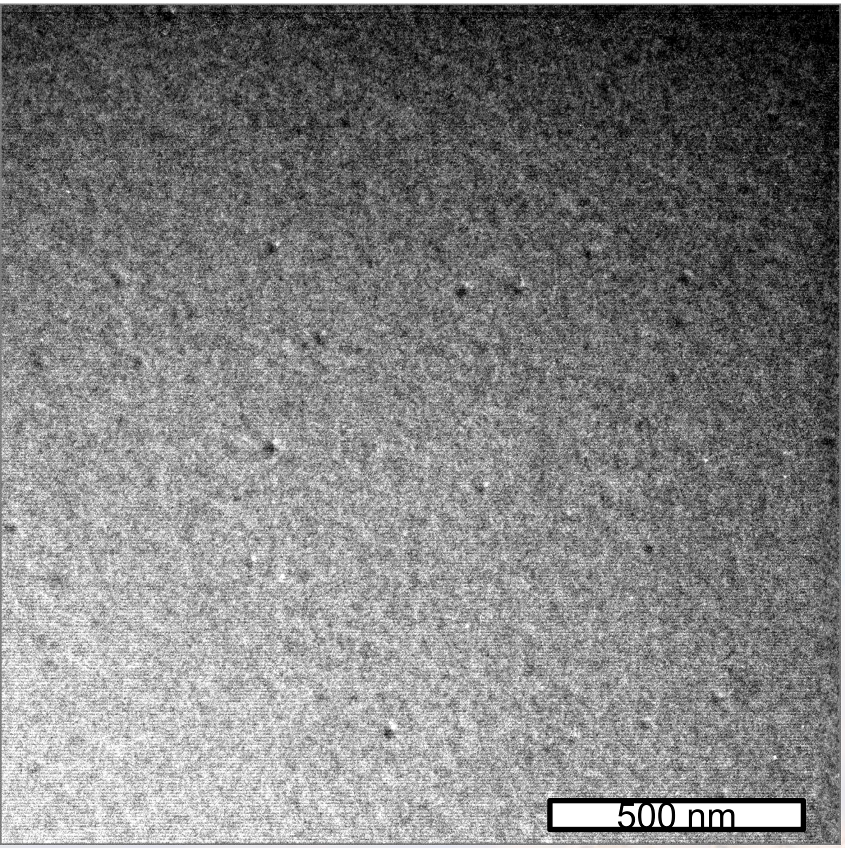
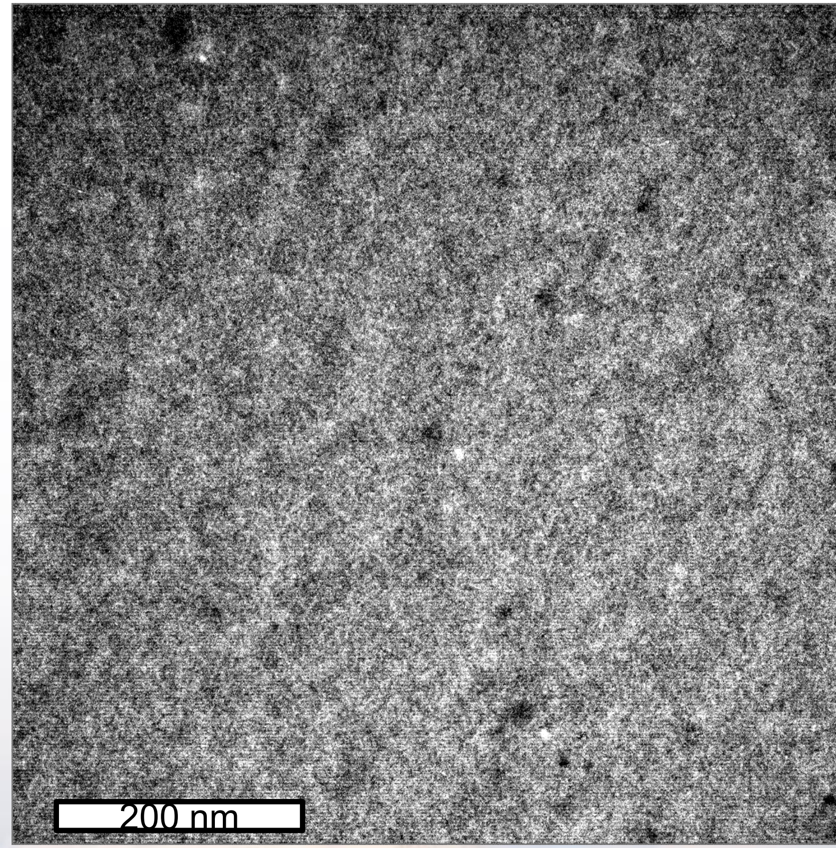
In-situ Annealing of Pristine and Irradiated GST

GST 0 %C
Anneal 5°C/min
100-150 °C
15x speed

No irradiation

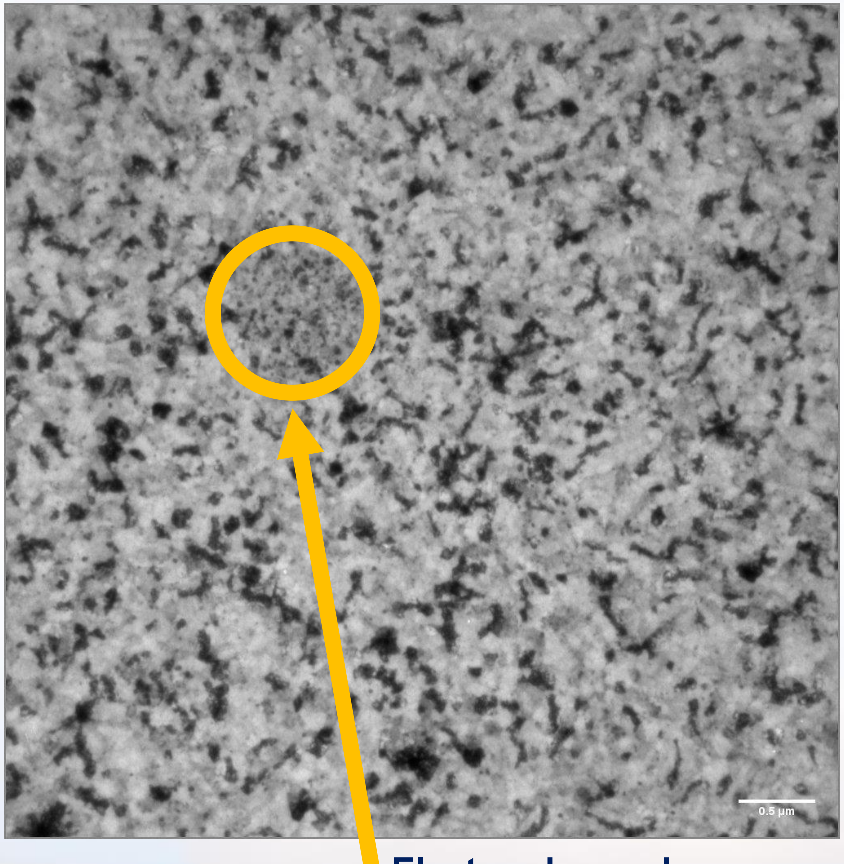


4 dpa



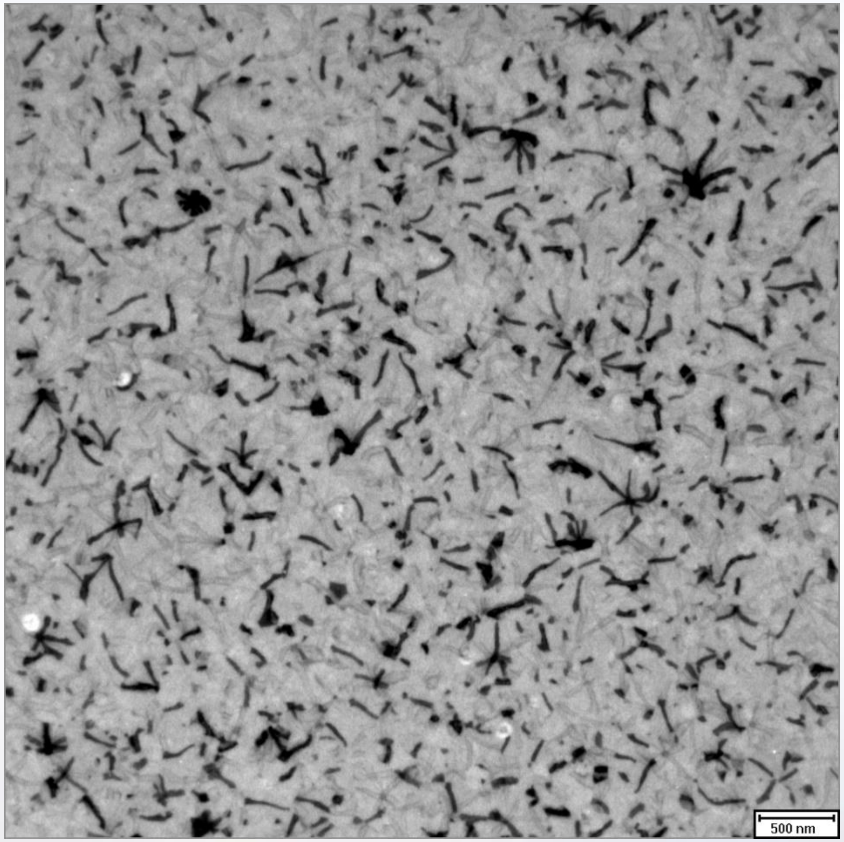
Crystallization temperature doesn't seem to change with ion irradiation

Electron Beam Induced Crystallization



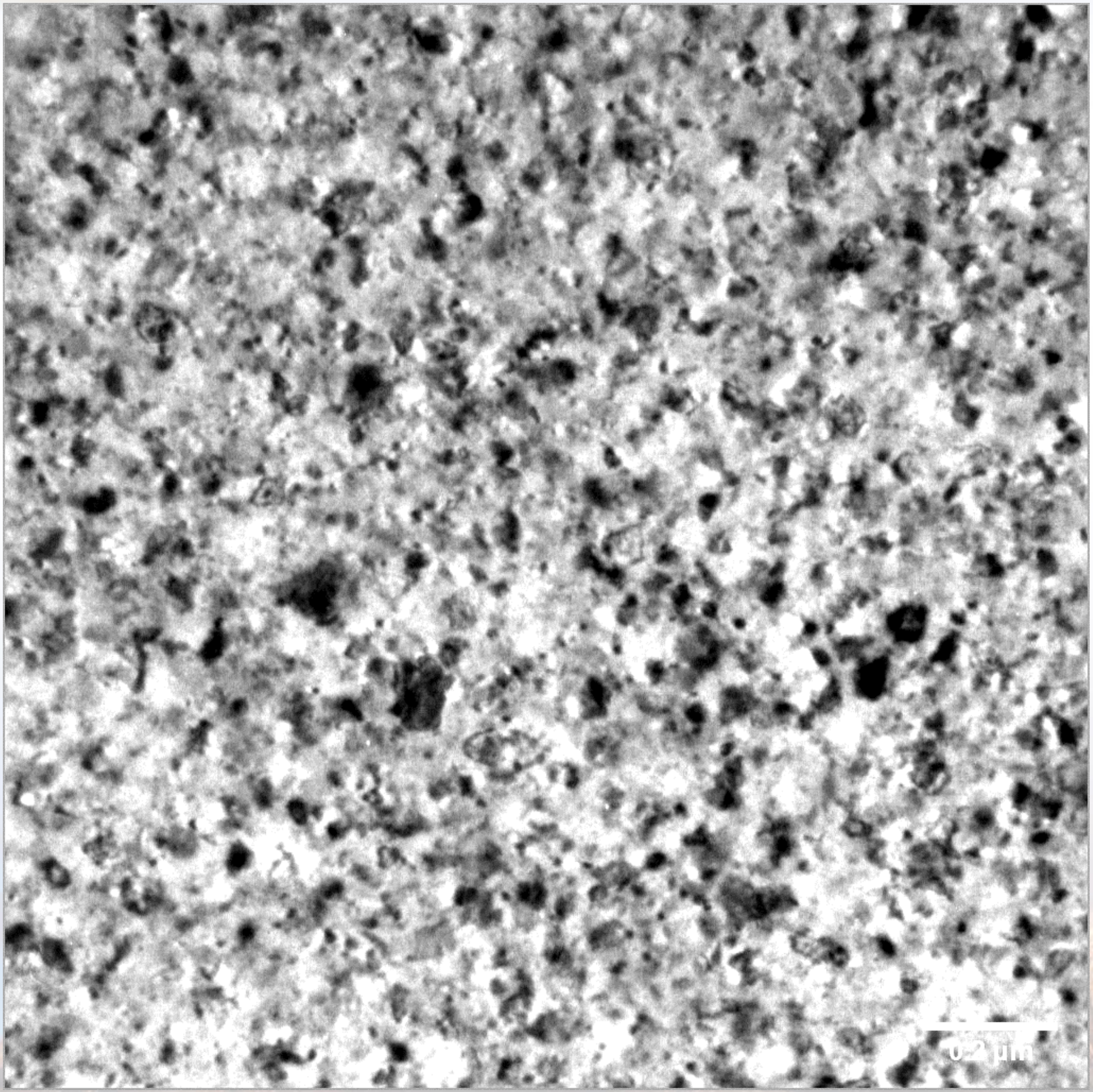
Electron beam damage

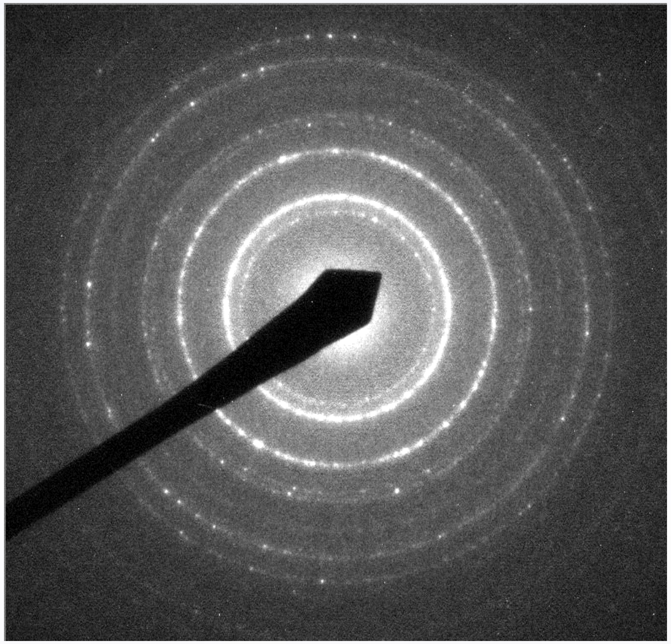
Atypical crystallization nucleated by condensed electron beam at RT Nanoscale grains ~20 nm.



Typical crystallization. Highly strained film with large grains ~500 nm. Contrast bands are bend contours.

GST 4 % C irradiated to dose of 1.5E14 ions/cm²





Displacement damage not visible by post-mortem investigation can be clearly seen during in-situ TEM ion irradiation

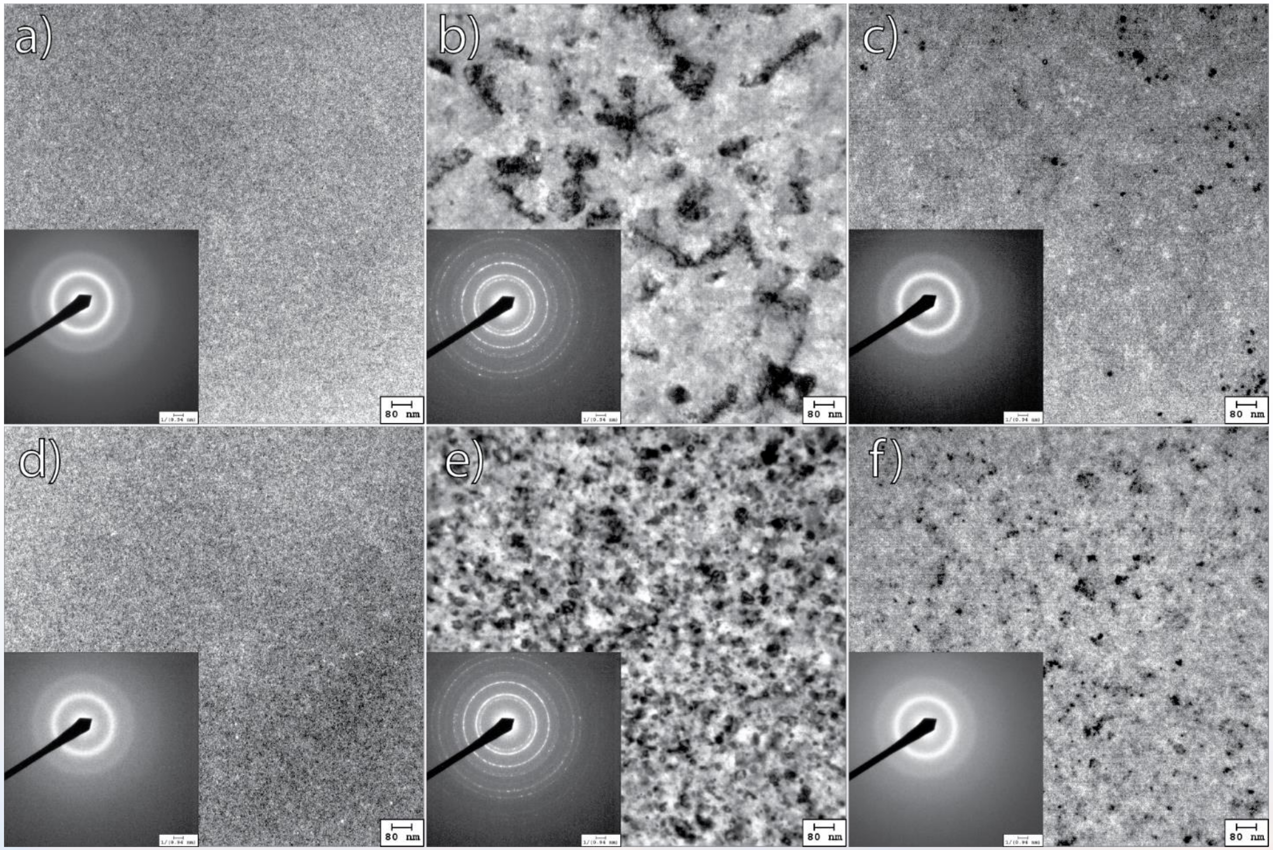
Sped up 24x

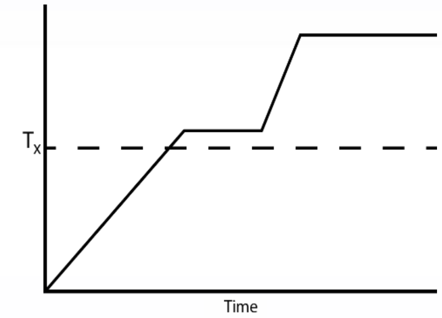
Representative Results

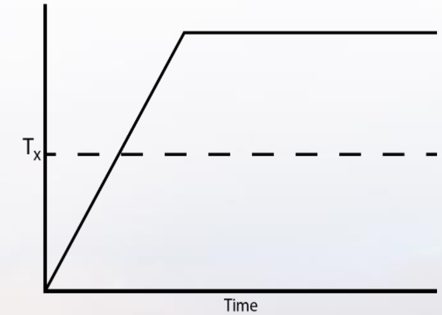
As-deposited | After Anneal | After Irradiation

0% C

2% C



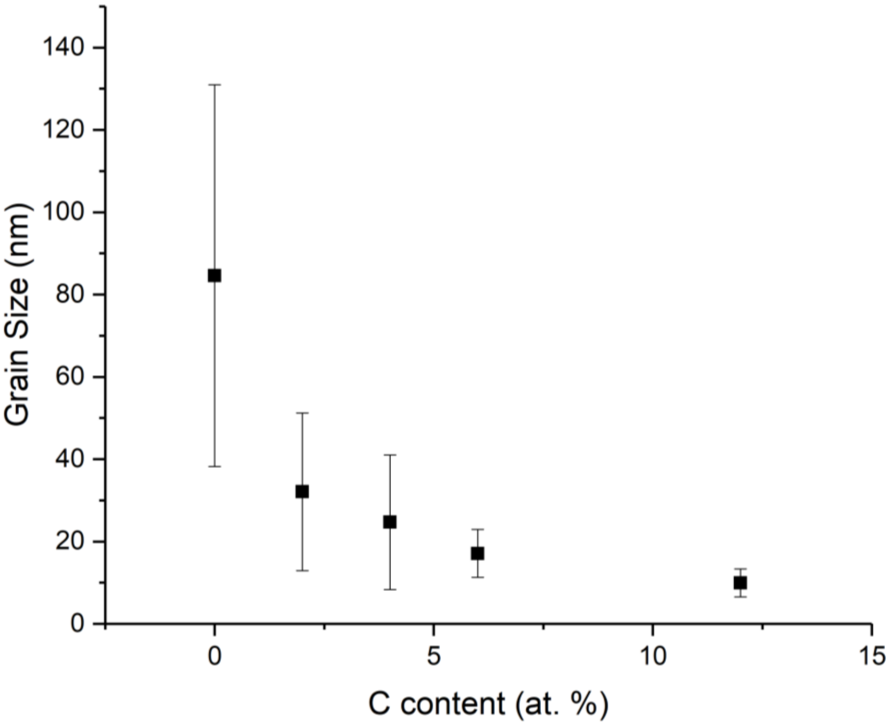


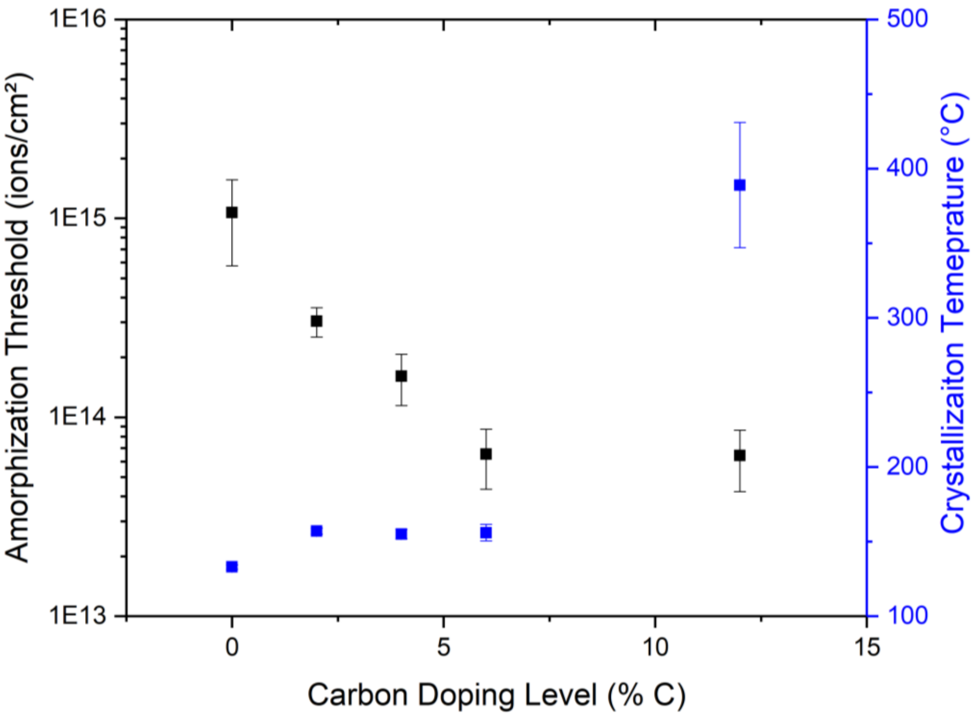


When annealing, holds close to crystallization temperature before high temperature anneal results in larger grains (b vs e)

Defects remain in the film after irradiation but produce no change to SAD pattern

Grain Size and Phase Evolution as a Function of Carbon Concentration

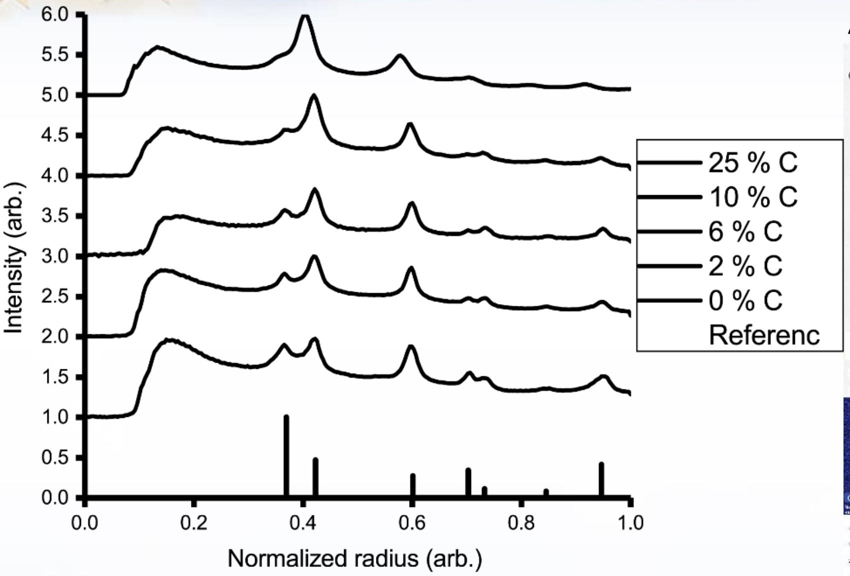




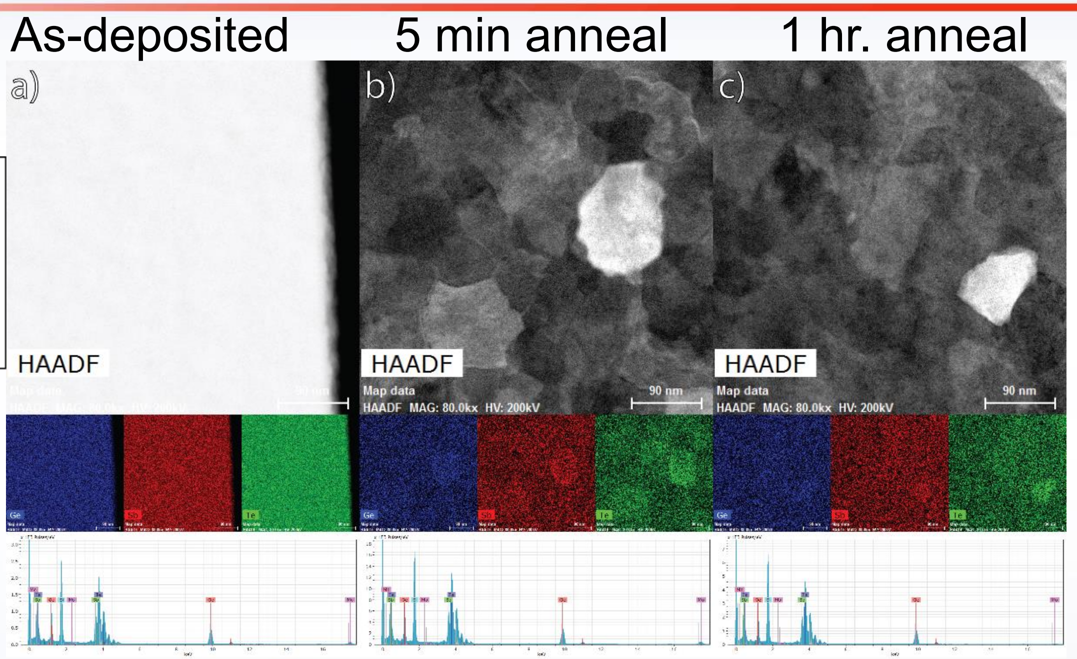
Grain size in the annealed state decreases with increasing C content

Amorphization and crystallization temperature are carbon dependent

Phase and Compositional Analysis



- Calculated by integrated radial intensity of SAED patterns.
- Peak indices: 111, 200, 220, 311, 222, 400, 420 (legend is nominal C content)



200 °C vacuum anneal at heating rate ~ 20°C/min

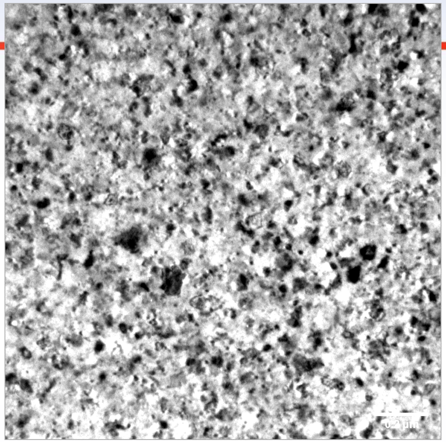
- Top: HAADF image
- Middle: EDS elemental map Ge (blue), Sb (red), Te (green)
- Bottom EDS spectra

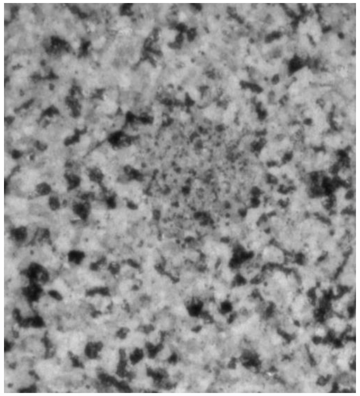
- **Single phase FCC crystals**
- **Slight decrease in lattice constant with increasing C content**

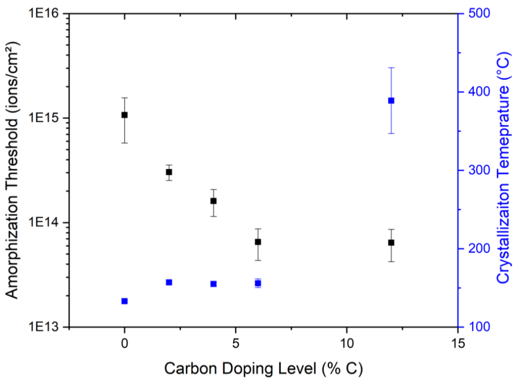
- **X-ray count ratios of Te/Ge and Sb/Ge did not change after the annealing.**
- **Indicating negligible loss of Te.**

Summary

- Amorphization damage threshold decreases with increasing C doping level
- Crystallization temperature increases with increasing C doping level
- Grain size in the annealed condition increases with increasing C doping level
- Potential beam heating of sample($7e\text{-}8 - 6e\text{-}7\ A/cm^2$ current density). COMSOL calculations can be used to estimate temperatures
- Increasing C may stabilize the amorphous phase







The stability of GST can be extensively explored via *in situ* TEM irradiation and heating

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Nuclear Science User Facilities

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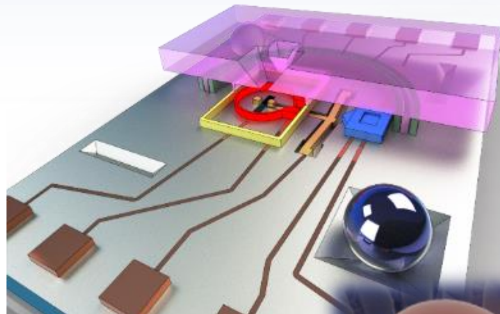
Sandia's User and Position <u>Opportunities</u>

D. Hanson, W. Martin, M. Wasiolek

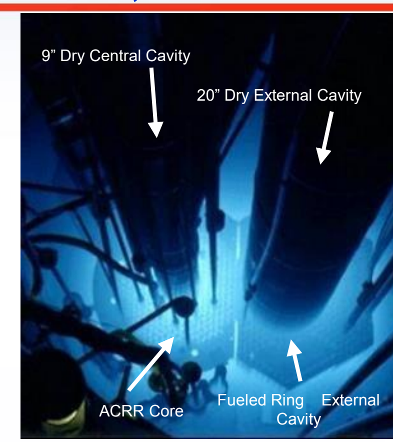
www.cint.lanl.gov

- Spring and Fall proposals for 18 months
- Rapid Access proposal anytime for 3 months



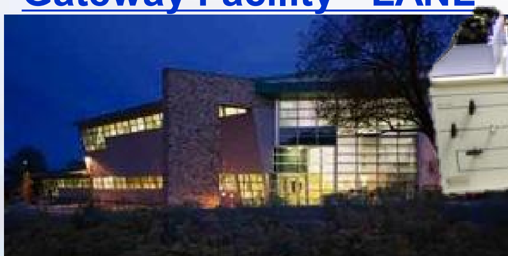
www.nsuf.inl.gov

- Three proposal a year for 9 months



Core Facility - SNL

Gateway Facility - LANL



Position Oppurtunities at:

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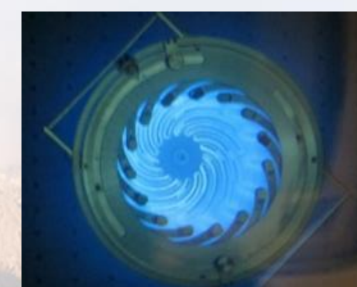
Post-doc = 671121

Grad Student = 670865

Undergrad Student = 670864



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