X-ray Diffraction studies of irradiated Materials at BNL Experimental Facilities - N. Simos (Oct. 9, 2014)

MATERIALS:
Graphite polymorphs, h-BN, Be, AlBeMet, Tungsten, Molybdenum, Glidcop, Mo-Gr, Cu-CD, carbon fiber composites, superalloys (Ti6Al4V, s-INVAR and gum metal) and metal-metal interfaces

Irradiations:

118-200 MeV Protons at BNL BLIP
Fast Neutrons at BNL BLIP
28 MeV Protons at Tandem
Neutrons at Tandem (low temperature)

X-ray Studies (completed)
(a) using monochromatic high energy X-rays
(B) high energy x-rays EDXRD (Phase I & Phase II)

MICROSCOPY (at CFN): SEM/EDS, annealing, DSC and TG/DTA
Spallation Neutron Irradiation at BLIP

[Graph showing normalized proton flux at BLIP target station]

Proton Distribution Profile - 120 MeV BLIP Proton Beam with Isotope Targets in Box-1

Spallation Neutron Profile generated by 120 MeV protons on Isotope Target Array in Box

3D profile produced by 200 MeV, 120 uA BLIP proton beam on LHC Collider Array (1) and Isotope Producing Target Array (2)
28 MeV Proton Irradiation at Tandem

Localized Damage Followed by EDXRD Studies
Multi-functional stage capable of handling
Real size irradiated specimens, under vacuum and four point bending state of stress
and eventually
Heating/annealing via a portable, collimated laser beam
Tensile stress-strain test

From concept to a versatile experimental stage at X17B1 beamline at NSLS
stress

strain
Good matching of experimental data
Transmission detector (radiography)

Ge-Detector

Diffraction volume

Like having imbedded inter-atomic strain gauges !!!!

\[ E_{hkl} \ [\text{in keV}] = \frac{6.199}{d_{hkl} \sin \theta} \]

\[ \varepsilon = \frac{\Delta d}{d_0} \]

\[ E = \frac{h}{\lambda} = \frac{h}{2\pi} k \]

\[ |k_{in}| = |k_{out}| = k \]

"White Beam"

\[ E_{hkl} (\text{in keV}) = \frac{6.199}{\sin(\theta) d_{hkl} (\text{in Å})} \]

\[ \varepsilon_{ii} = \frac{d - d_0}{d_0} \]
Graphite

Important to know what occurs during irradiation and post-irradiation annealing (mobilization of interstitials/vacancies)

This is what we observe in BULK
What happens at the crystal level?
How is E is affected or is strain in crystal related to bulk?
Interstitial defects will cause crystallite growth perpendicular to the layer planes (c-axis direction).

Coalescence of vacancies will cause a shrinkage parallel to the layer planes (a-axis direction).
Graphite Various grades, including Carbon fiber composites under different irradiations

This 002 peak also broadens asymmetrically, with a bias towards smaller angles indicating an increase in average interlayer distance. The (002) diffraction spot also broadens in single crystal images, suggesting a range of values for the interlayer distance.
Goal is to correlate post-irradiation annealing observed macroscopically with shifts observed in XRD

Global volumetric changes vs. crystal-level changes

Activation Energy
Interstitial defects will cause crystallite **growth** perpendicular to the layer planes (c-axis direction)

Coalescence of vacancies will cause a **shrinkage** parallel to the layer planes (a-axis direction)