Advanced Material Studies for High Intensity Proton Production Targets and Windows

Sujit Bidhar[1], Shunsuke Makimura[3] , Andrew Casella[5], David Senor[5], Dohyun Kim[6] , Eiichi Wakai[2]
Frederique Pellemoine[1] , Marco Calviani[4], Katsuya Yonehara[1] , Kavin Ammigan[1], Ram Prabhakaran[5]
Ram Devanathan[5],Sho Kano[7], Shin-ichiro Meigo[2],Yosuke Iwamoto[2], Takashi Wakui[2]

[1]Fermi National Accelerator Lab,IL,USA ; [2]Japanese Atomic Energy Agency, Japan; [3]KEK, Tsukuba, Ibaraki, Japan; [4]CERN, Geneva, Switzerland; [5]Pacific North West National Lab, Richland, USA , [6]Brookhaven National Laboratory, NY, USA, [7]The University of Tokyo, Japan

Thermal shock experiment at CERN- HRMT-60

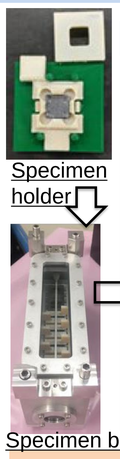
Successfully carried out thermal shock on promising materials in October 2022. Both pre-irradiated and unirradiated samples were tested.

- Future accelerator materials put to their limit to check survivability.
- Study effect of radiation damage on thermal shock resistance.
- Real time dynamic measurement of compressive stress wave on materials.

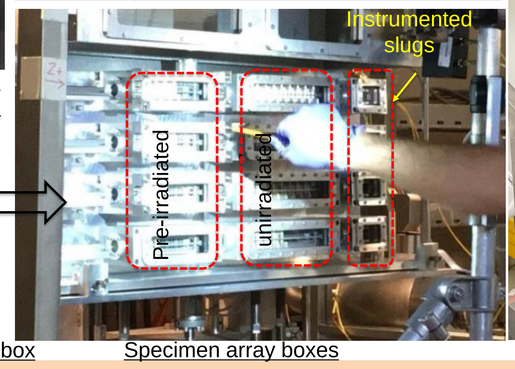
List of materials tested : (120 Specimen, 4 instrumented slugs)

Unirradiated : Graphite(POCO-ZXF5Q,IG430),zirconia nanofiber,Beryllium,Sigraflex, Ti6Al4V, Timet 1100, Ti6246,Ti15-3, DAT54, High-Entropy Alloys, TFGR, pure W, NITE-SiC
Irradiated : Graphite (POCO-ZXF5Q, IG430), MoGr, Sigraflex, Beryllium,Ti6Al4V, Ti15-3

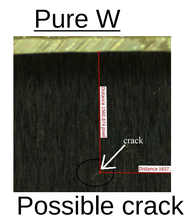
Experimental Set up

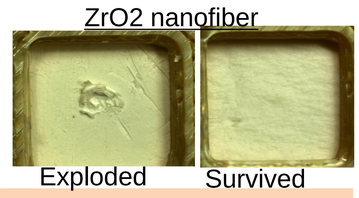


Energy	p/bunch	Bunches	Beam-σ
440 GeV	1.3x10^{11}	288,216,72,24	0.25mm

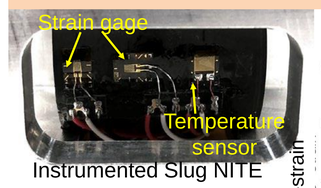


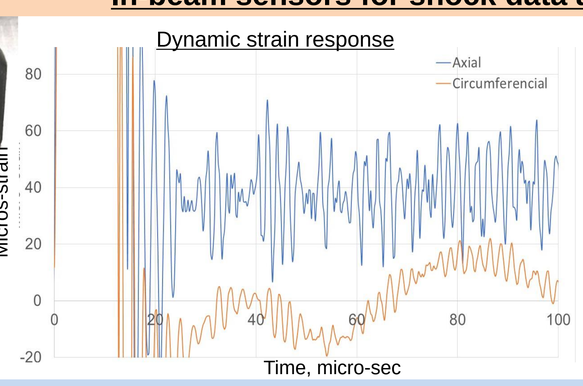
Post Thermal shock

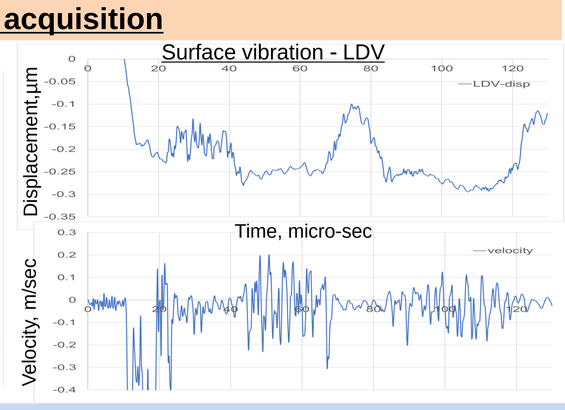




In-beam sensors for shock data acquisition

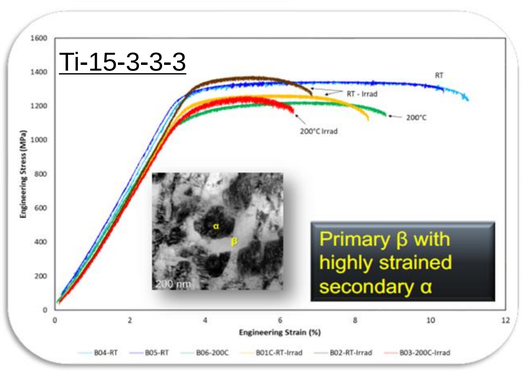




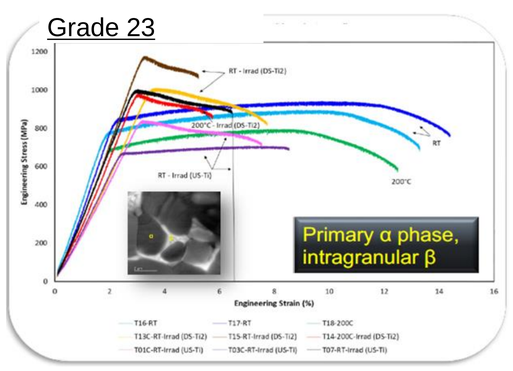


Radiation damage studies

Tensile Test



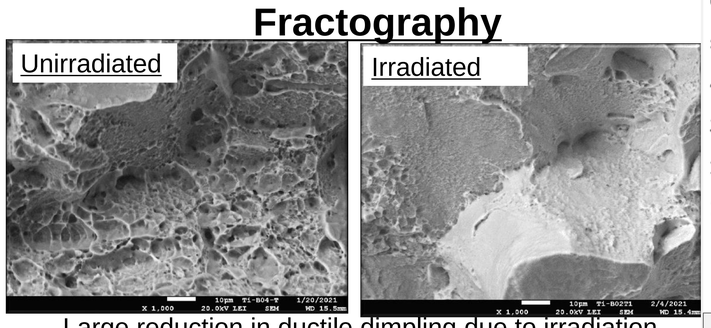
Grade 23



Objective : To evaluate proton irradiation impact on mechanical properties

- Ti-15-3 has highly strained dual β/α microstructure resistant to
- Radiation damage upto 1dpa. No ω-phase evolution in β-phase
- Hardening and loss of ductility in Grade 23 due to irradiation induced defects in α-phase inhibiting dislocation movements.

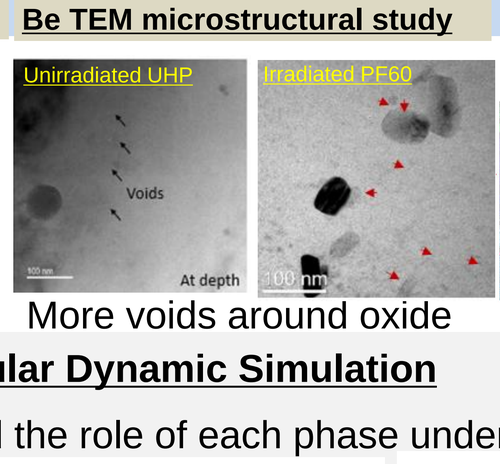
Fractography



Large reduction in ductile dimpling due to irradiation

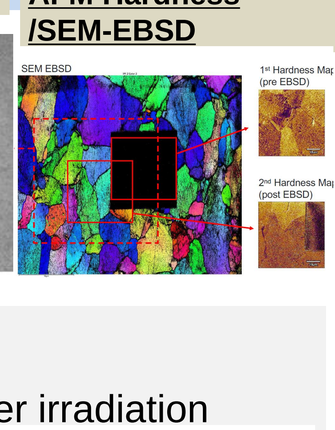
Be Bend Test in Hot cell

Be TEM microstructural study



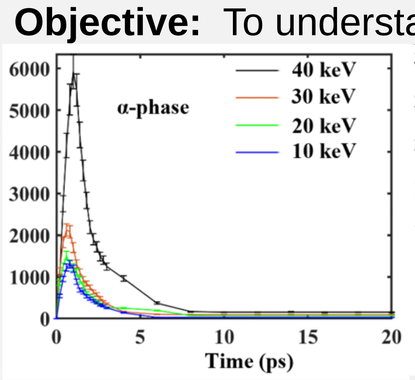
More voids around oxide

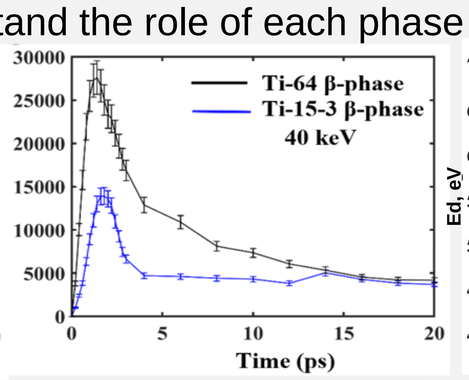
AFM Hardness /SEM-EBSD

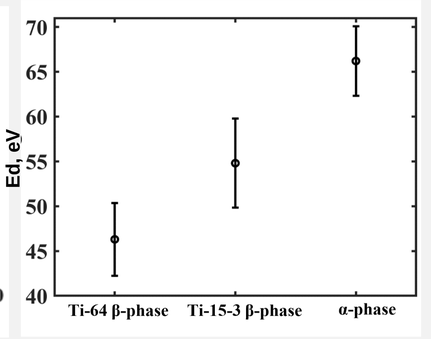


Molecular Dynamic Simulation

Objective: To understand the role of each phase under irradiation







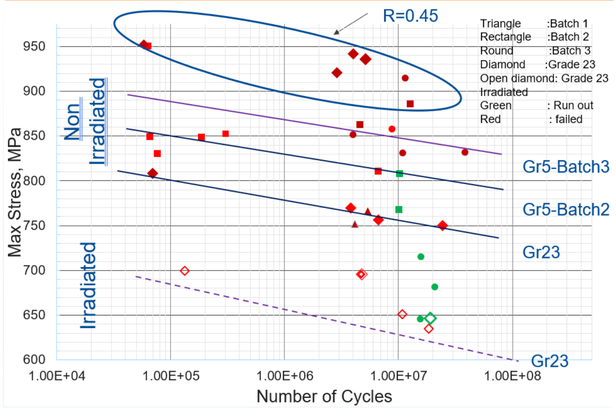
Simulations of collision cascades to compare the formation of point-defects in the two alloys

Displacement threshold energies estimated

Fatigue

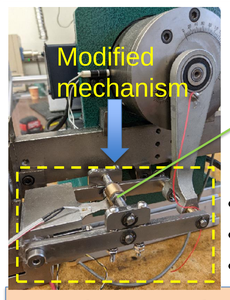
Objective: Effect of proton irradiation on fatigue life of Ti6Al4V

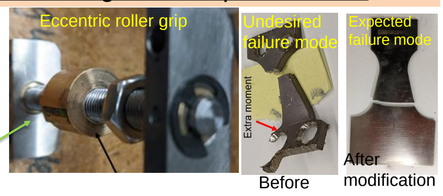
Ti6al4V Hight Cycle Fatigue life



- First ever demonstration of fatigue life on proton irradiated Ti6al4V
- Reduced life due to irradiation

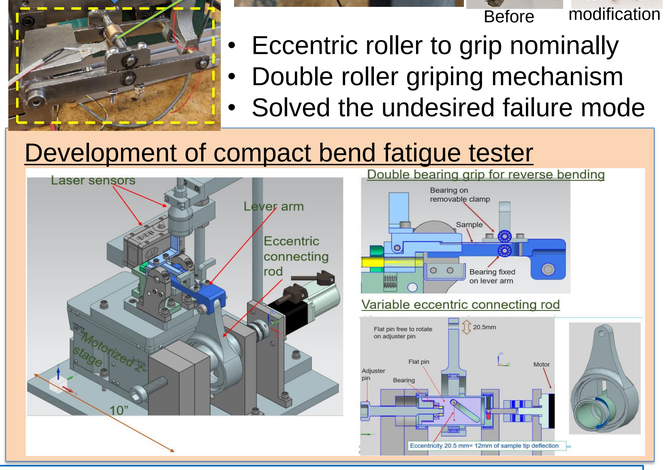
Improvising commercial fatigue tester performance





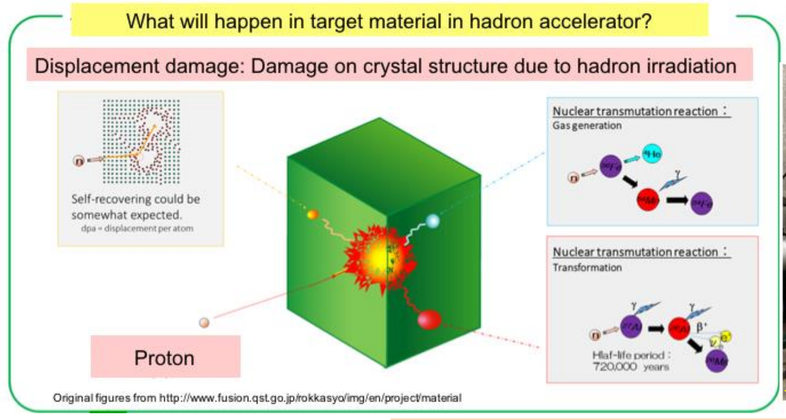
- Eccentric roller to grip nominally
- Double roller griping mechanism
- Solved the undesired failure mode

Development of compact bend fatigue tester

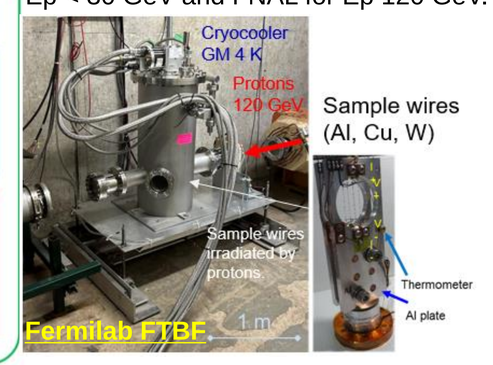


DPA cross-section measurement

Objective: Experimental measurement of displacement cross section in high energy regime and compare with simulation model



Experiments conducted at J-PARC for Ep < 30 GeV and FNAL for Ep 120 GeV.

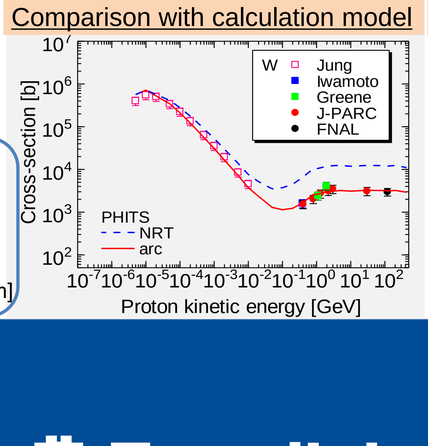


For the first time, measurement done in high energy region

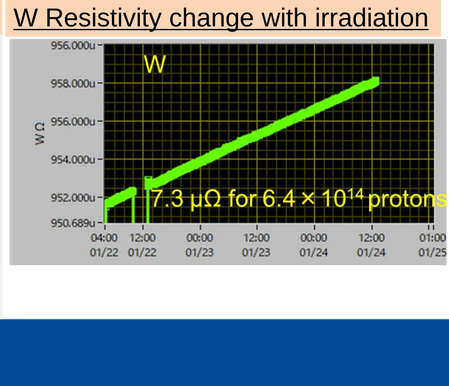
$$\sigma(E) = \Delta\rho/(\phi \cdot \rho_f)$$

σ(E): Displacement cross section [b]
Δρ: Change of resistivity [Ω/m]
Φ: Fluence of incident protons [/cm^2]
ρ_f: Resistivity change by Frenkel pair [Ω/m]

Comparison with calculation model



W Resistivity change with irradiation



Acknowledgements:
This research is supported by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 and US-Japan Science and Technology Cooperation Program in High Energy Physics. In addition, the European Commission under the FP-7 Research Infrastructures project EuCARD-2, Grant Agreement No. 312453, and European union's Horizon 2020 research and innovation program under grant agreement no. 730871, provided support for this experiment.

RaDIATE Collaboration
Radiation Damage In Accelerator Target Environments

Fermi National Accelerator Laboratory
Email: sbidhar@fnal.gov