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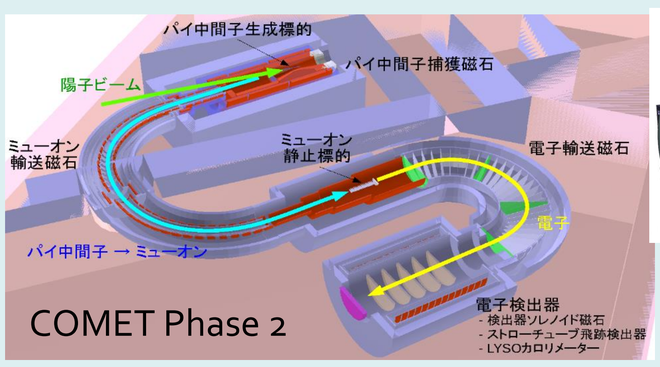
J-PARC, KEK

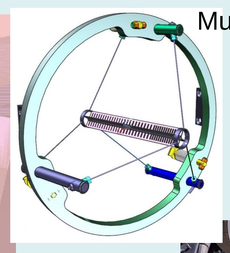
J-PARC Center, KEK & JAEA
Fermi National Accelerator Laboratory, CERN & RaDIATE collaboration
Metal Technology Co. Ltd & SUNRIC Co., Ltd. & Yumex Co., Ltd.
Ehime University & Kyushu Institute of Technology & The University of Tokyo
IMS & NIFS, National Institutes of Natural Science Research Institute for Applied Science

Developments in Toughened Fine-Grained Recrystallized Tungsten for High Intensity Proton Production Targets

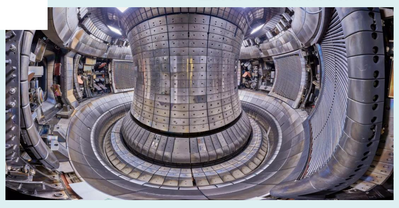
The US-Japan Science and Technology Cooperation Program in High Energy Physics
"*Advanced Material Studies for High Intensity Proton Production Targets and Windows*"

Tungsten — Target material for proton accelerator




Mu2e target


ESS website

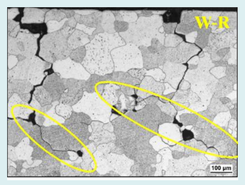

Eurofusion

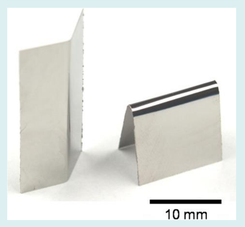
- J-PARC COMET Phase 2 Target, Mu2e Target
- J-PARC MLF 2nd Target Station, ORNL SNS 2nd Target Station
- ESS Neutron source, CERN Anti-proton target, Future target
- (Diverter: Fusion reactor materials)

☐ High density: Low spatial volume of secondary particles on target
☐ High melting point: Available beam power is high.

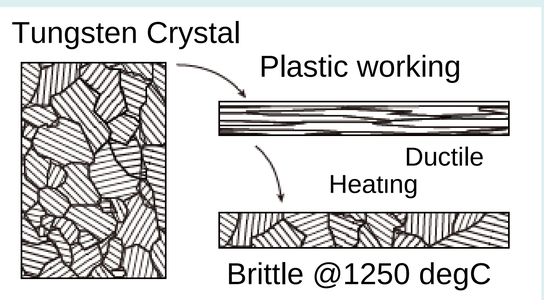
Recrystallization embrittlement

Limitation in high temp. use





Grain boundary fracture (G. Pintsuk et al.)



J.Reiser et al. JNM, 423 (2012) 1.

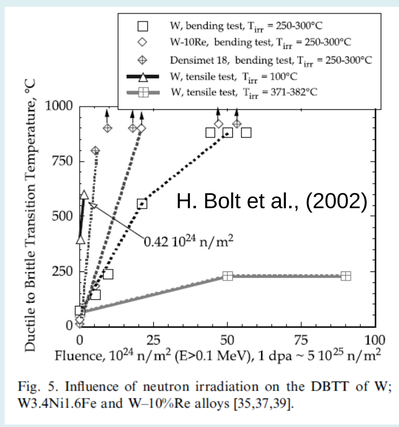
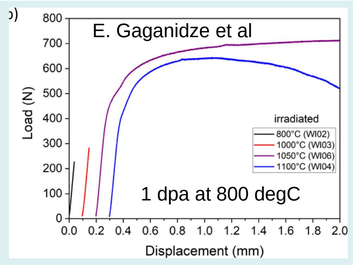


Fig. 5. Influence of neutron irradiation on the DBTT of W; W3.4Ni1.6Fe and W–10%Re alloys [35,37,39].



Ductile-brittle transition temperature (DBTT) increases by very small dpa.

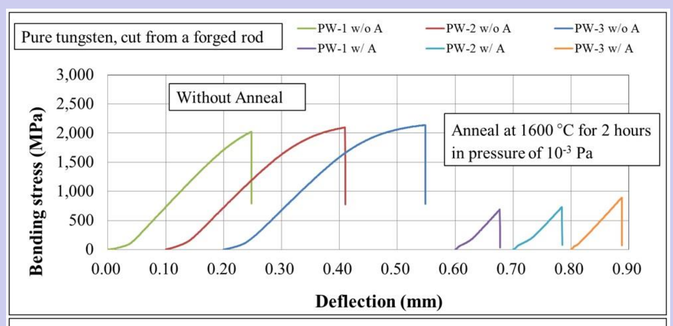
Irradiation embrittlement

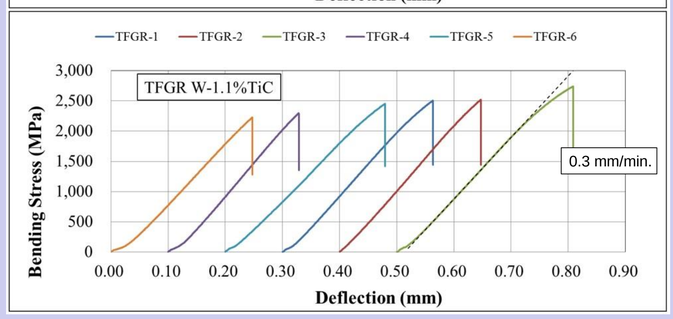
Limitation in Irradiation environment

Toughened Fine-Grained Recrystallized Tungsten

Overcoming recrystallization embrittlement – *Achieved!!*

H. Kurishita et al., Mater. Trans. 54 (2013) 456-465.

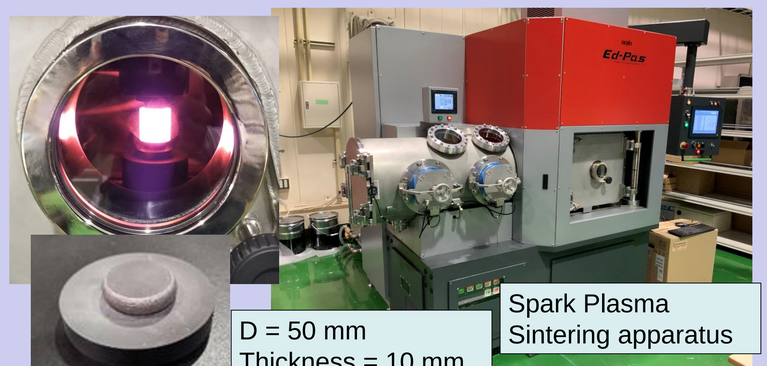




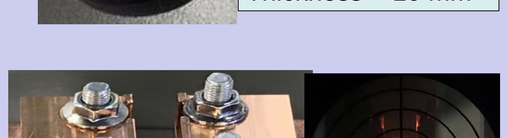
S. Makimura et al., Mater. Sci. Forum, Spallation Materials Technology, 1024(2021)103-109

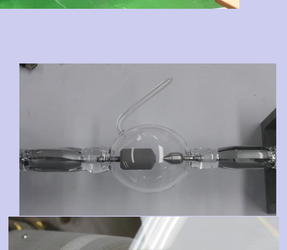
- Grain boundaries are reinforced by segregation of titanium carbide.
- After 1650 C heating, TFGR-W shows high bending strength and ductility.

Ultra high purity glove box




3D-ball milling apparatus
Vacuum mechanical alloying


Study for heater application

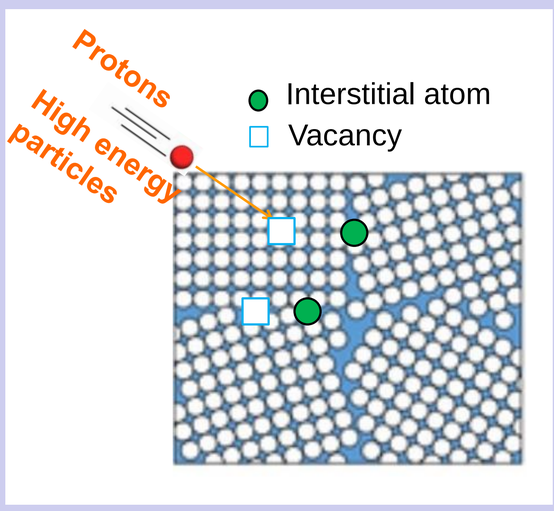

Study for short-arc lamp

Academic-Industrial collaboration

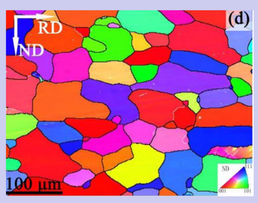
Manufacturing environment

US-JP & RaDIATE collaboration

Overcoming Irradiation embrittlement

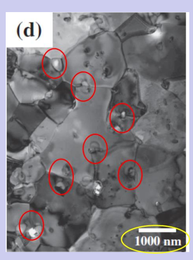


- Grain boundaries absorb the defects by irradiation.
- Fine-grained material is radiation-resistant.



Kang Wang et al.

100 μm @ ITER-g W
After 1300 ° C annealing



1-2 μm @ TFGR W
After 1650 ° C annealing
H. Kurishita et al.

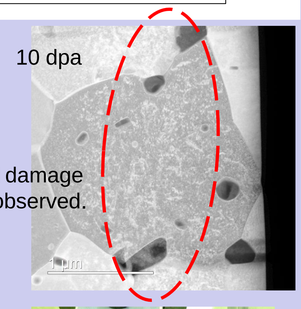
Why TFGR-W ?

Material fabrication → High but local damage by Ion irradiation

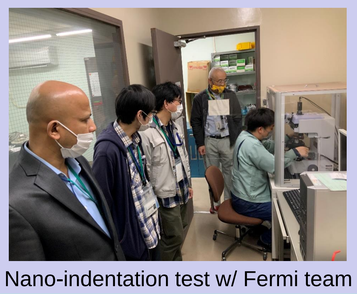
Post Irradiation Examination
➢Nano-hardness meas.
➢Microstructure analysis

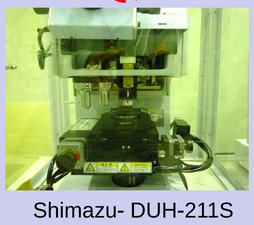
Material selection for proton beam irradiation tests

Ion irradiation at HIT facility

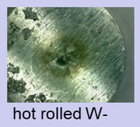


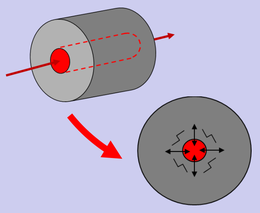
Local damage was observed.

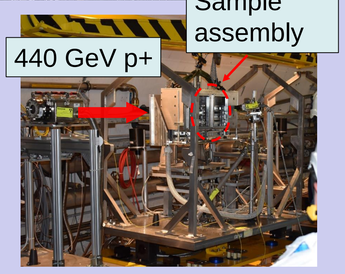

Nano-indentation test w/ Fermi team


Shimazu- DUH-211S


Hot rolled W

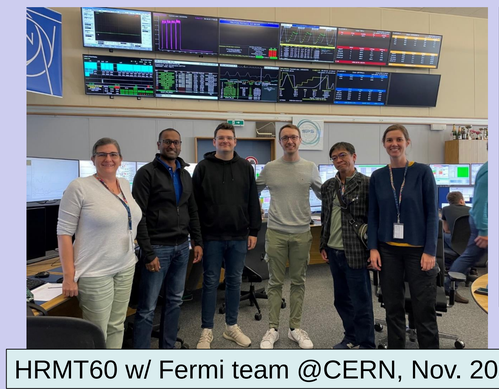

hot rolled W-recrystallized
C. T. Martin et al


Instantaneous heat & stress wave




W-TiC- with GSMM

TFGR survived at HRMT48 !!

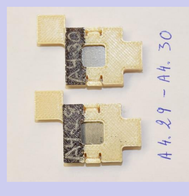

HRMT60 w/ Fermi team @CERN, Nov. 2022

■ HRMT 48:
dT=500-700 K
σ= 1 GPa

PIE @PNNL soon.

■ HRMT 60:
dT=1950 K
σ= 1.4 GPa

Thermal shock experiment at CERN HiRadMat



Pure W
TFGR W-TaC
After irradiation