Novel Materials and Concepts for Next-Generation High Power Targetry

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HEP High-Power Targetry Roadmap – Targets and Sources

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Advancing the state-of-the-art in target materials and concepts

- Operate at higher beam power and intensity, and improve ability to convert primary beam into secondary particles of interest
- Enhance reliability and lifetime of targetry components to maximize uptime of target facilities
  - Targets, beam windows, beam dumps, collimators, etc.
- Enable next-generation multi-megawatt accelerator facilities (>10 years)
  - LBNF 2.4 MW, Mu2e-II, FCC, ILC, neutron sources, etc.
- Develop radiation damage and thermal shock tolerant materials
  - Leading cross-cutting challenges facing high-power target facilities
- Develop new targetry concepts and technologies to cope with higher power

Novel materials R&D

- High-Entropy Alloys (HEAs)
  - Multi-component alloys for accelerator applications (beam windows)
  - Shown to have improved radiation damage resistance
  - Broad range of alloy systems that can be explored
  - R&D efforts recently started at Fermilab (DOE ECRP support)
- Electrospun Nanofiber Materials
  - Ceramic and metallic nanofiber materials for secondary-particle production targets
  - To improve radiation damage and thermal shock resistance
  - Initial LDRD project and ongoing effort with DOE ECRP at Fermilab

Novel materials R&D

- SiC-coated graphite and SiC-SiC composites
  - For improved oxidation resistance at high temperatures
  - Higher efficiency of secondary particles transport
  - Ongoing R&D at KEK and within the RaDIATE collaboration
- Toughened Fine-Grained Recrystallized (TFGR) Tungsten
  - Muon/neutron production target
  - R&D effort to reduce embrittlement of W (at low temperature and after recrystallization)
    - Investigating grain boundary reinforced nanostructures (TFGR)
  - Ongoing R&D at KEK and within the RaDIATE collaboration

Novel materials R&D

- Dual-Phase Titanium Alloys
  - Ti-6Al-4V commonly used for beam windows
    - Good strength, ductility and corrosion resistance but properties degrade significantly under neutron/proton irradiation
  - R&D efforts ongoing to improve fatigue life and radiation damage resistance
    - Microstructural control by thermomechanical treatment, 3D printing, investigation of advanced dual-phase Ti alloys, improved corrosion resistance using coatings (TiN, TiAlN)
- Advanced Graphitic Materials
  - 2D/3D carbon/carbon, Mo-C reinforced composites to improve thermal/electrical properties
  - Ongoing R&D at CERN and within the RaDIATE collaboration

Novel targetry concepts and technologies

- Rotating, flowing and circulating targets
  - Rotating targets (FRIB, ESS) for high power beam operation
  - Significant R&D needed on flowing and circulating solid targets (Mu2e-II, Muon collider, etc.)
    - Granular target, conveyor target, fluidized powder target, …
    - Some R&D effort at STFC RAL and Fermilab
  - R&D of flowing liquid metal targets (ORNL SNS, MLF)
    - Address cavitation erosion and fatigue issues to allow higher beam power

Novel targetry concepts and technologies

- Advanced cladding materials and technologies
  - Diffusion bonding of dissimilar materials with HIP methods (eg. cuprous materials to SS)
    - For enhanced heat transfer to cope with increased power deposition (beam dump and absorbers)
  - Advanced cladding techniques for W and Mo-alloy (TZM) with Ta and Ta2.5W
  - Other cladding materials R&D: Zircalloy, Nb-alloys, TZM
  - Continued investigation and PIE of cladding breach and radiation damage effects
  - Ongoing R&D at CERN and ISIS Neutron and Muon facility

Novel targetry concepts and technologies

- Targety geometry and composition optimization
  - Need to initiate effort in this area
  - Using Monte-Carlo and FEA simulations together with Machine Learning techniques to optimize the target system
    - Fine tune target shape and composition (eg. variable density) to increase efficiency
- High-heat flux cooling methods
  - Need to initiate R&D to address heat removal challenges
    - Explore unconventional heat transfer techniques
      - Controlled boiling (hyper-vapotron), radiative cooling, other methods…

Novel HPT materials and concepts

- Successful development and validation of these novel materials and target technologies will strongly depend on:
  - Material irradiation capabilities using prototypic or alternative beams (radiation damage and thermal shock tests)
  - Post-irradiation material characterization techniques (hot cells and testing equipment)
  - Modeling capabilities