Collimator Materials for High Density Energy Deposition

Adriana Rossi on behalf
Outlook

- EuCARD2 for materials: collaboration
- A brief overlook on accelerators
- Motivation of material studies and methodology
ColMat-HDED collaboration and beyond

- ColMat-HDED partners

- Partnership agreement with CERN (KN2045)

BREVETTI BIZZ

- Collaboration CERN with US-LARP
• Our goal is to investigate the dynamics and structure of matter.

• To study the collisions of quarks with each other, scientists resort to collisions of nucleons, which at high energy may be usefully considered as essentially 2-body interactions of the quarks and gluons of which they are composed.

• We accelerate charged particle beams to extremely high energy, in a confined way and make them collide.

• Particles travel in a ultra-high vacuum tube and are guided by magnetic fields (in the LHC SC magnets)
LHC

- LHC beam energy density up to 15 GJ/mm²
- Collimation system to ‘clean’ beam halo (regular losses)
- Protect machine (accidental losses)
- Beam dump

Robustness
Including protection devices, a **5-stage cleaning** is required! The system performance relies on achieving the well-defined **hierarchy** between collimator families and machine aperture.
Impedance:

Impedance in Accelerator Physics is a quantity that characterizes the self interaction of a charged particle beam, mediated by the beam environment.

- In the lab frame, the EM field of a relativistic particle is transversely confined within a cone of aperture of $\sim 1/\gamma$.
- Particle accelerators operate in an ultra high vacuum environment provided by a metal vacuum chamber.
- By Maxwell equations, the beam’s E field terminates perpendicular to the chamber (conductive) walls.
- An equal image charge, but with opposite sign, travels on the vacuum chamber walls following the beam.

- As long as image current travels at c, forces cancel out.
- Resistive walls slow image current $\Rightarrow$ wakefield interacts with beam and modifies particle motion.
- Need of low impedance materials.
Beam instability

- Instability could be driven by impedance (amongst all different causes)

Break-up instability in an electron linac is shown below:

From: Collective Instabilities in Accelerators Alex Chao 赵午 OCPA School 2010
Motivations

• Accelerator performance with ever increasing beam brightness and stored energies pushes material requirements for collimators into more challenging grounds: Collimators (and all Beam Intercepting Devices) are inherently exposed to extreme conditions.

  – Higher robustness (LHC beam energy density up to 15 GJ/mm², 2-3 orders > other machines).
  – Lower impedance, by far, the highest impedance machine is the LHC machine itself, potentially leading to serious machine instabilities.
  – Larger resistance to radiation (1E16 p/year doses in LHC betatron cleaning insertion).
  – Higher absorption (clean efficiency for machine protection).

Many requirements shared with a broad range of applications requiring efficient Thermal Management.
Material studies

Experimental:
- Material characterisation (pristine)
- Irradiation
- Beam impact
- Thermo-mechanical tests

Thermo-mechanical and beam simulations

Radiation damage simulations
- Materials being investigated are Copper-Diamond (Cu-CD), Molybdenum-Diamond (Mo-CD).

- Molybdenum-Graphite (Mo-Gr) is particularly appealing for it can be coated with a Mo layer dramatically increasing electrical conductivity, easily machined, has better thermal properties ...

- R&D program still ongoing to further improve physical properties, particularly mechanical strength of Graphite.
Potential range of applications outside accelerators

Can be further expanded thanks to the tailoring possibilities of Molybdenum-Graphite composites ...

Courtesy of A. Bertarelli
Later presentation will show methodology and results

THANK YOU FOR YOUR ATTENTION
Back up slides
Experimental setup

SETUP 01

- Induction heating system
- Heating solenoid
- Cooling jet
- Control thermocouple
- Thermocouple

SETUP 02

- Induction heating system
- Heating solenoid
- Pyrometer gage length
- Infrared pyrometer
- Fast camera
- Infrared camera
- Thermocouple
At Politecnico di Torino, dynamic measurements performed to determine the **effects of temperature and strain rate on the material behaviour**

Characterization of metallic alloys with the Split-Hopkinson bar experimental setup:

- Inermet180 (W-alloy) completed
- Molybdenum (2 grades) completed
- Densamet (W-alloy) ongoing

Constitutive models to be used to predict material behaviour under extreme conditions (high strain rate, high temperature)
Irradiation tests to study ion-induced modifications with ion fluencies and perform.

Microstructural studies – SEM

![Mo-Gr](image1.png)

![Cu-CD](image2.png)

*Courtesy of M. Tomut*
Experimental characterisation

- GSI irradiation tests with swift heavy ions

In-plane and transverse MoGr samples irradiated at ≈ Bragg peak energy with Au → U ions, with doses from 1E11 to 5E13 ions/cm².

- All investigation methods (Laser Flash Method, Raman Spectroscopy, SEM, X-ray diffraction) show better stability if samples annealed prior exposure (so far 1150°C and 1300°C - 1800°C yet to be measured).
- There seem to be a threshold dose for damage (to be understood).
- Maximum irradiation dose should not be reached at LHC.
- Irradiation above ion track formation.

At higher accumulated doses the transverse samples are deforming, whereas the in-plane samples experience no change of the shape. Optimization of radiation hardness of these samples has been done by pre-irradiation annealing.
After $5.10^{13} \text{ions/cm}^2$ – Au $5.9 \text{ MeV/u}$

Transverse cut

- All 3 grades exposed to $5.10^{13}$ Au ions/cm$^2$ broke due to beam induced deformation.

- At $2.10^{13}$ Au ions/cm$^2$ samples show different degree of deformation, depending on the C fiber content.

- Analysis is ongoing
SEM images of the Cu-CD composite after p+ irradiation at 30 MeV and dose of $10^{17} \, \text{p/cm}^2$ with (a) – high and (b) – low magnifications.
Studies @POLITO

- Development of strength and failure models for relevant materials
- Fracture analysis of novel composites materials
- Contributions to the development of Equations of State for relevant materials

Courtesy of L. Peroni
- Novel, composite materials are under development to meet these challenges.
- New sophisticated and powerful numerical tools (Hydrocodes) are used to simulate accidental events. Limitations exist as to material constitutive models.
**Thermo-mechanical measurements @CERN**

- **State-of-the-art machines** purchased by CERN to measure thermal properties of advanced materials
- **Temperature range**: $T_{room}$ up to 2000 °C (lower limit -180 °C with ad-hoc setup)
- **Laser-Flash**: thermal diffusivity, specific heat and thermal conductivity
- **Dilatometer**: Coefficient of thermal expansion

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**Graphs**
- **MoGr // fibres**
- **MoGr ⊥ fibres**

*Courtesy of F. Carra*
Method to measure material properties @CERN

- CTE measurements: measurements performed in the two directions, after heating/cooling cycles
- Dotted lines: CTE
- Continuous lines: linear expansion

Dilatometer

MoGr // fibres, CTE

MoGr ⊥ fibres, CTE
THANK YOU FOR YOUR ATTENTION