GSI: Possible Contributions to WP11 and Work Proposals

EuCARD2 WP11.2 (Materials for Collimation) tasks meeting

10.12.2013

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- GSI contributions in WP 11:

11.2. Material testing for fast energy density deposition and high irradiation doses (M. Tomut)

11.3. Material response modelling:

  - Hydrodynamic codes (N. Tahir, need of simulations for our own HDED experiments using lasers and ion beams)
  - FEM modelling (starting at GSI with a Ph.D. student, possible collaboration with CERN and Torino)

Advanced collimator materials characterization & testing at high irradiation doses

Material irradiation and damage characterization in situ and postirradiation;

- Irradiation at energy close to the Bragg peak (UNILAC) and at high energy (SIS)
- online studies: thermography, SEM, resistivity
- post irradiation studies:
  - thermography off-line – cyclic excitation for visualization of stress concentrators
  - characterization of mechanical properties degradation as a function of dose using micro- and nanoindentation: hardness, Young modulus, impact resistance, fatigue behaviour, creep
  - thermal conductivity – LFA
  - microstructural characterization: SEM, Raman, XRD

11.2/3 Material testing and simulations for fast energy density deposition

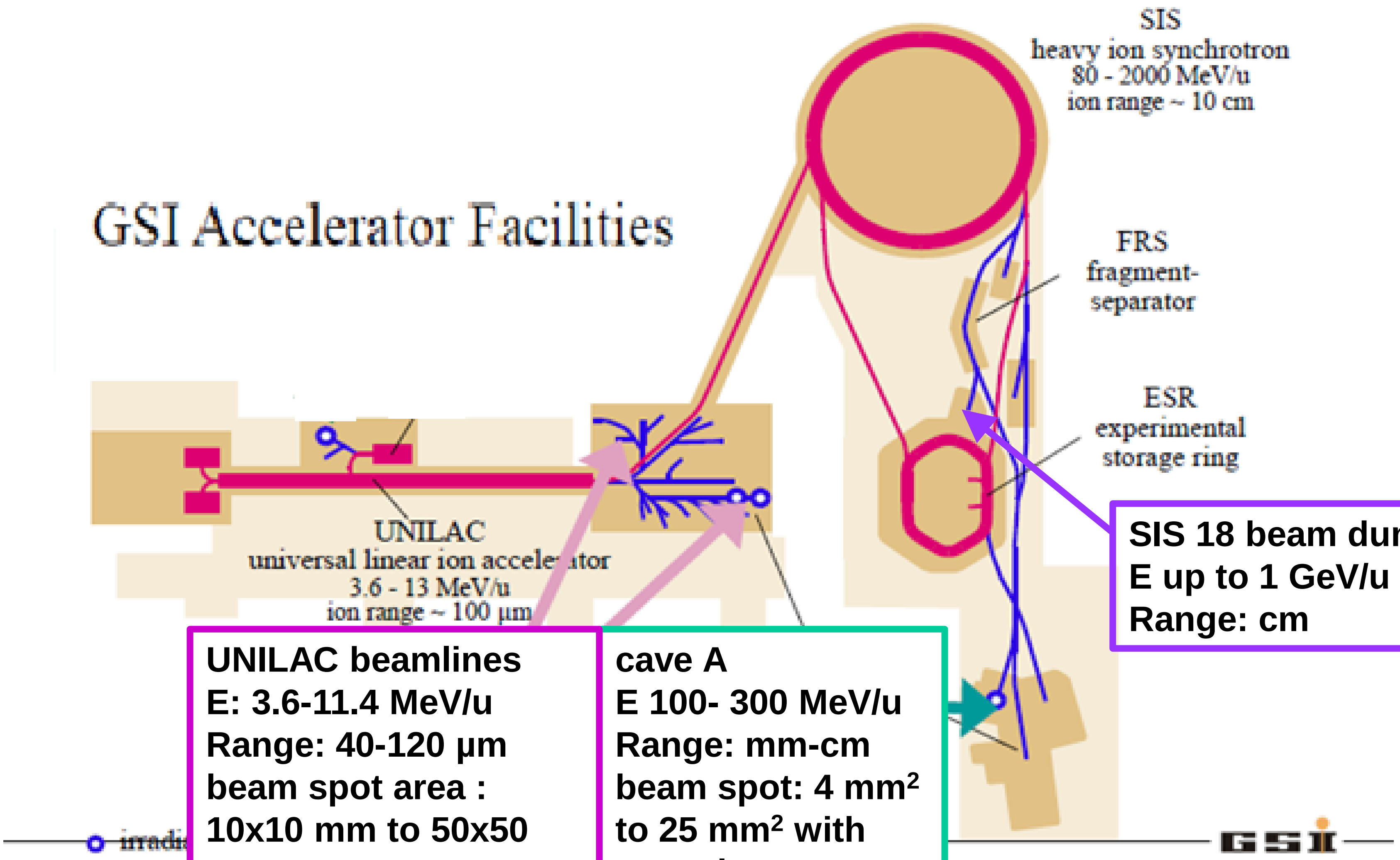
Material testing for fast energy deposition:

- single impact
  - impact nanoindentation
  - pulsed ion beams,
  - ns pulse laser generated proton beams
  - other in situ possibilities still open
  - spall strength studies at high strain rates in:
    - graphite, ….
    - model composite materials by thin layered structures:

      Copper – diamond, Mo- graphite
- fatigue studies with high/low duty cycle

Material testing at high irradiation doses

Beamlines for material research irradiation at GSI



UNILAC beamlines
E: 3.6-11.4 MeV/u
Range: 40-120 µm
beam spot area : 10x10 mm to 50x50 mm

cave A
E 100- 300 MeV/u
Range: mm-cm
beam spot: 4 mm^2 to 25 mm^2 with scanning

SIS 18 beam dump
E up to 1 GeV/u
Range: cm

UNILAC: beam parameters

3.6 / 4.8 / 5.6 / 8.6 / 11.4 MeV/u typical energies

50 Hz Mode (Penning, ECR)

50 Hz

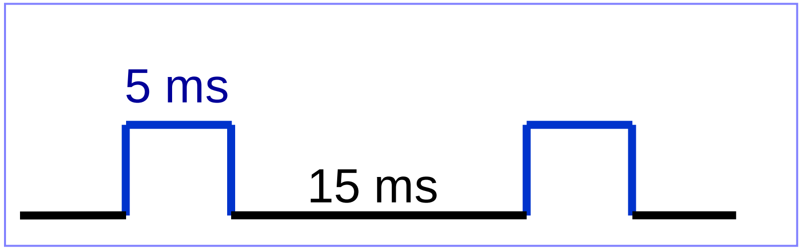
5 ms length of macropulse

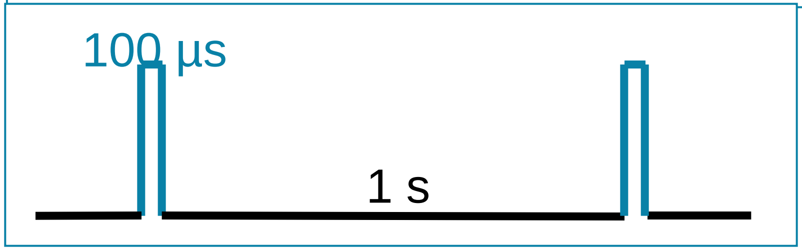
high-current mode (MEVVA source)

(for SIS experiments)

1-2 Hz

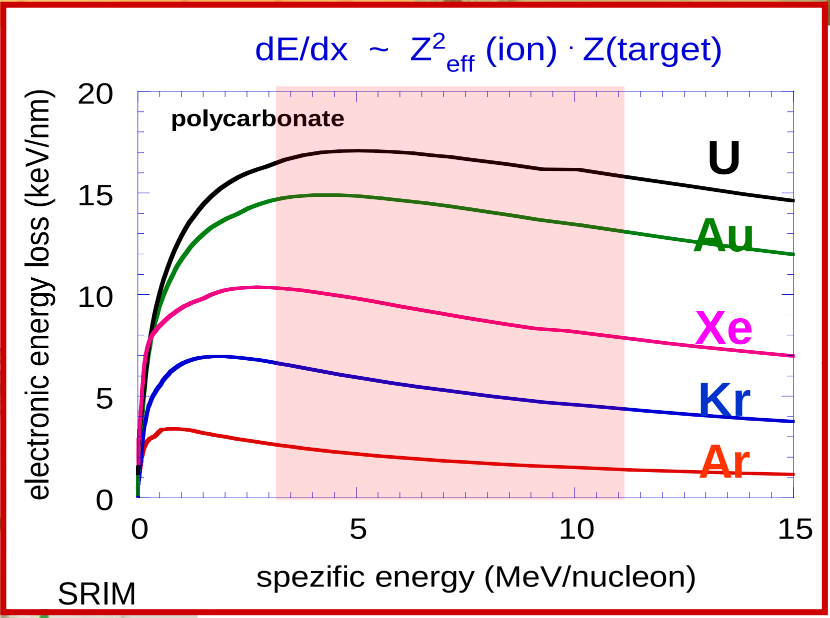
100-200 µs length of macropulse



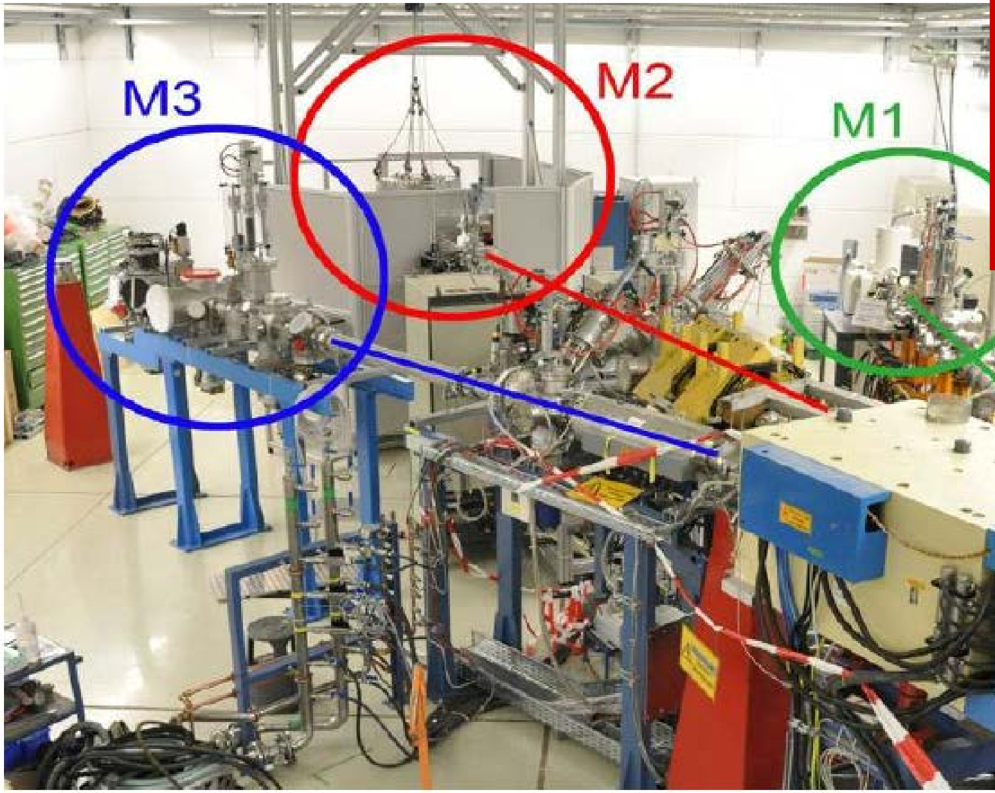


M-branch irradiation facility at GSI
In situ experiments

- energies close to Bragg peak:
  - to maximize energy deposition and damage
  - to avoid activation



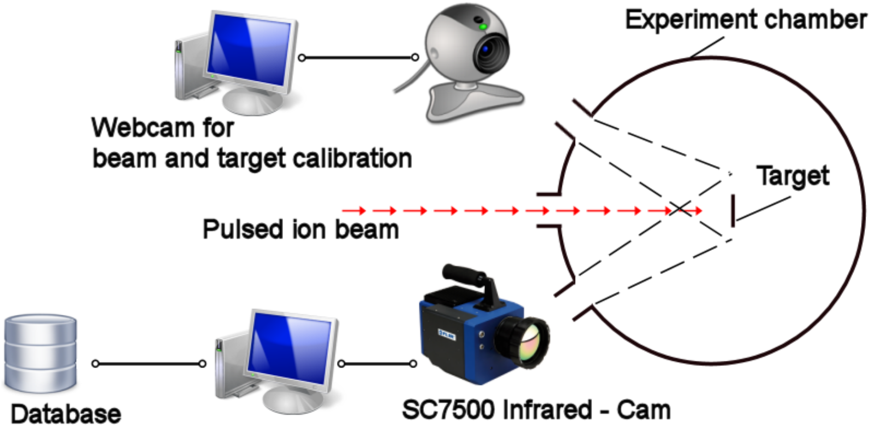
SRIM code

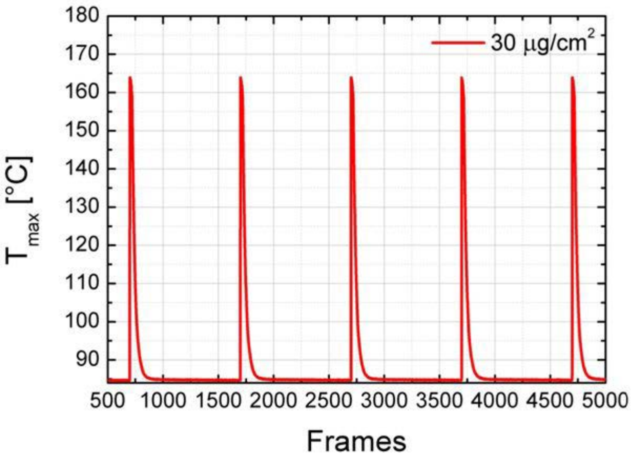


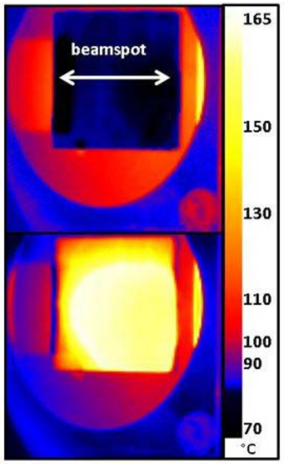
ion species
..C…Xe...U
flux:
up to10^{10} ions/cm^2 s

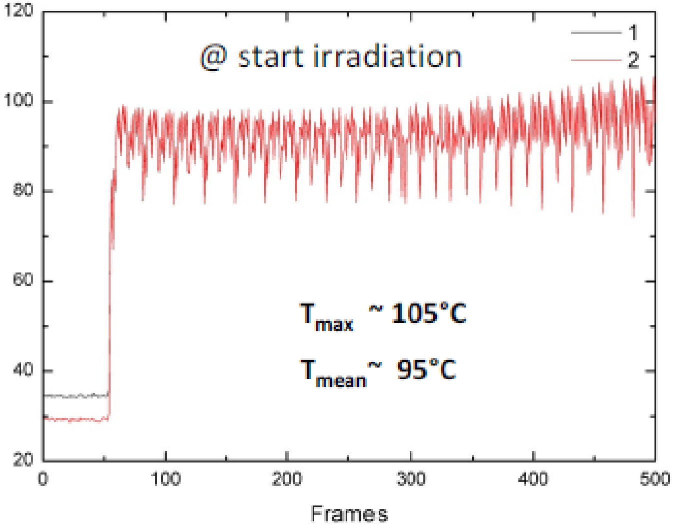
Online thermography using a fast high sensitivity IR camera

M3
High temperature irradiation
Online monitoring:normal and IR camera
Online resistivity measurements- in progress

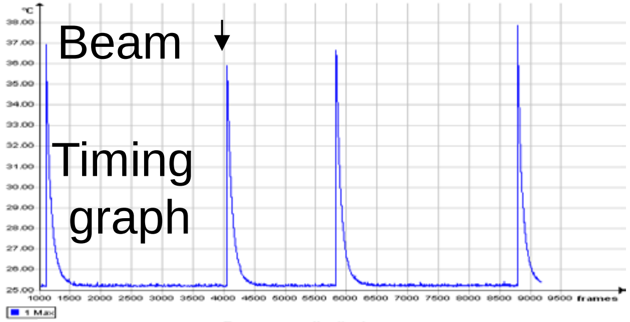


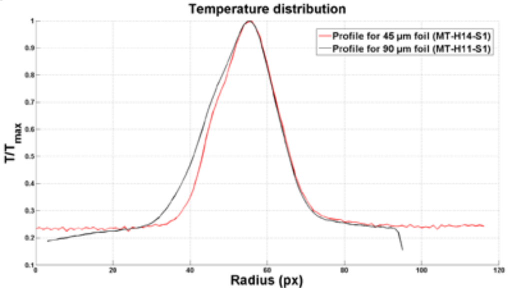


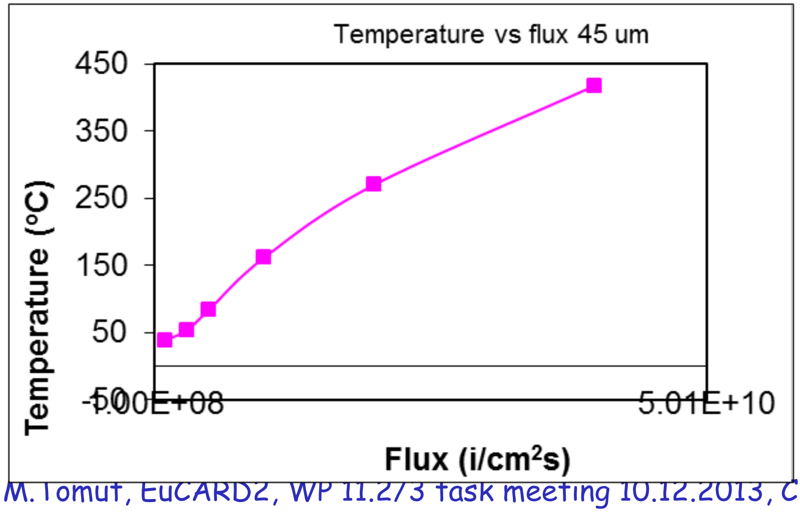




Beam monitoring on targets by IR thermography

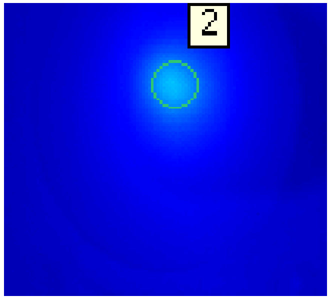




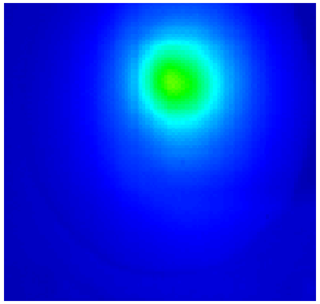


IR images of beam spot on thin graphite targets UNILAC experiments

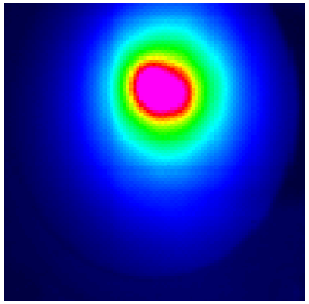
1E9 i/cm^{2}s



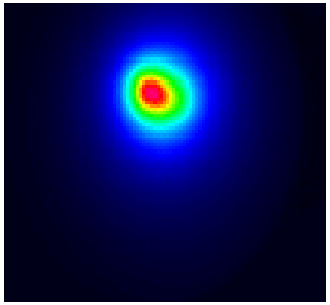
3E9 i/cm^{2}s



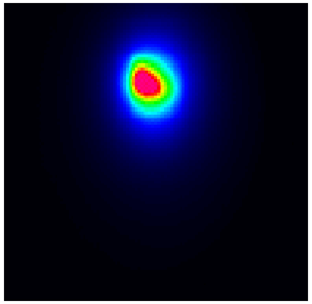
5E9 i/cm^{2}s



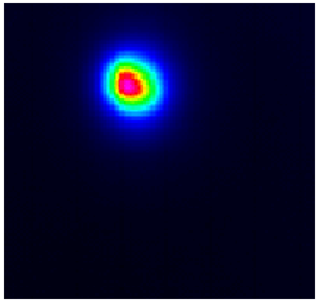
1E10 i/cm^{2}s



2E10 i/cm^{2}s



4E10 i/cm^{2}s

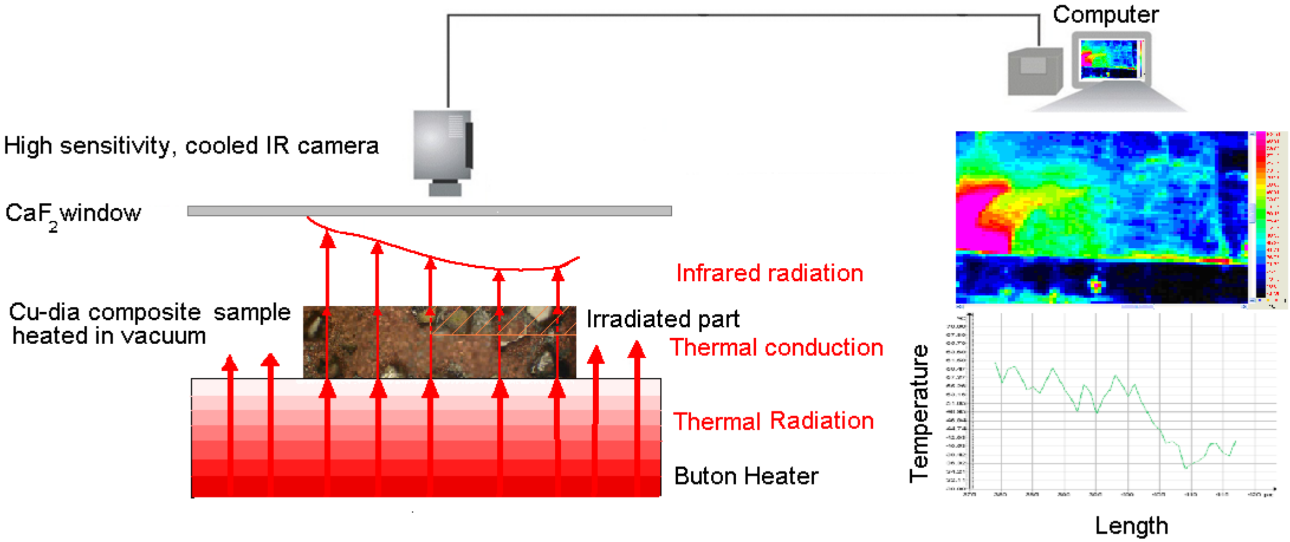


IR monitoring of thermal conductivity degradation of copper diamond composite

Proposed experiment:
thermal conductivity and thermal resistance degradation at interfaces during irradiation of new collimator materials

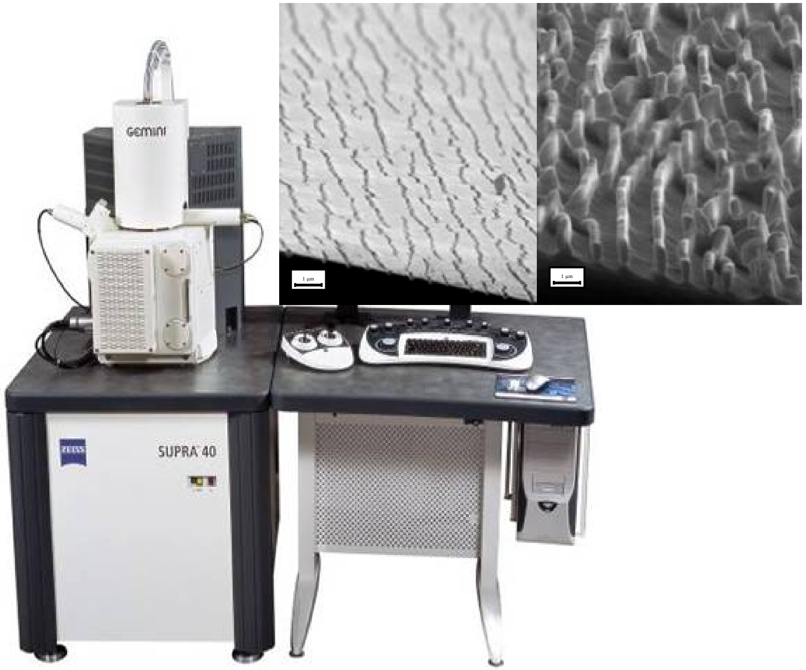
Preliminary offline test:

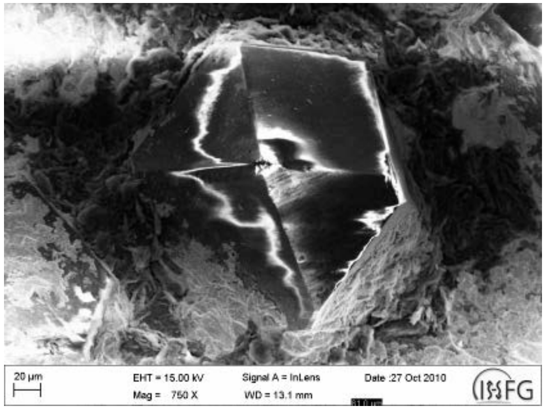
Post-irradiation IR imaging tests of thermal conductivity degradation in copper-diamond composites exposed to high doses of 4.8 MeV/u ^{197}Au ions at M-branch,



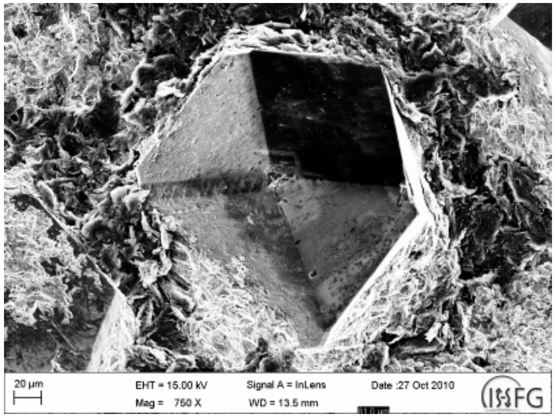
Online and in situ analysis HR-SEM facility at GSI-UNILAC

M1
Electron Microscopy





1×10^{13} i/cm^2

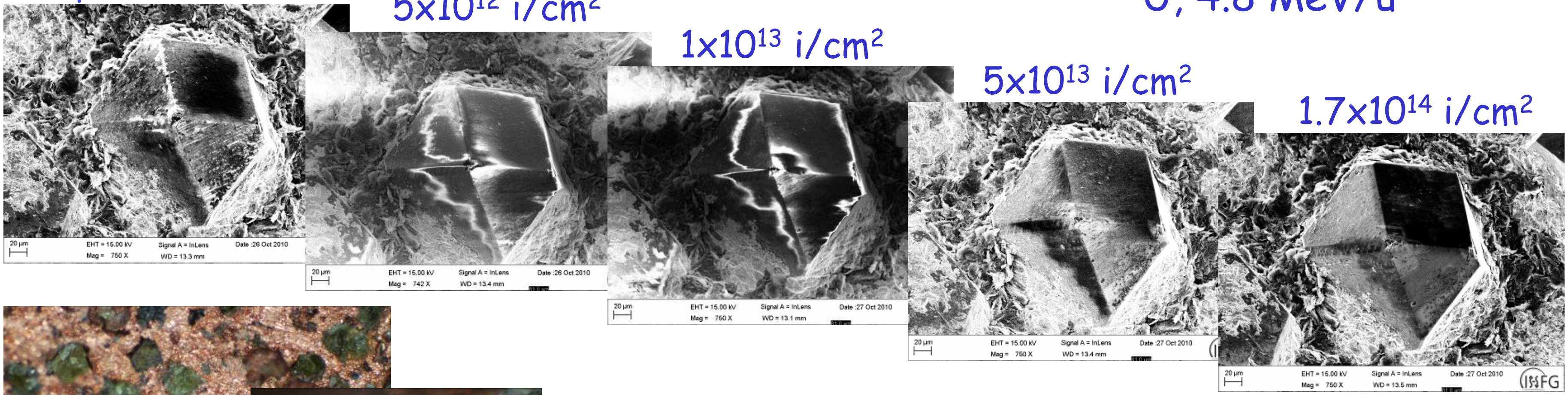


1.7×10^{14} i/cm^2

in collaboration with University of Stuttgart,

In situ SEM monitoring of heavy ion irradiation effects in novel copper-diamond composites

^{238}U, 4.8 MeV/u



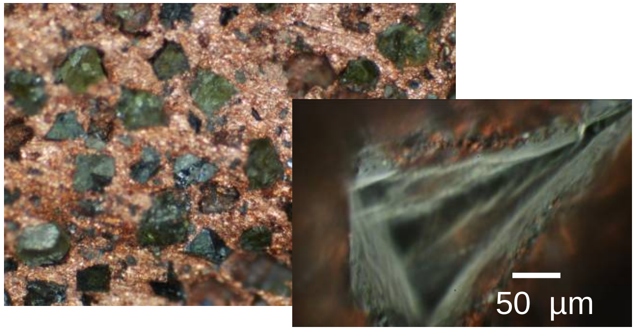
pristine

5x10^{12} i/cm^2

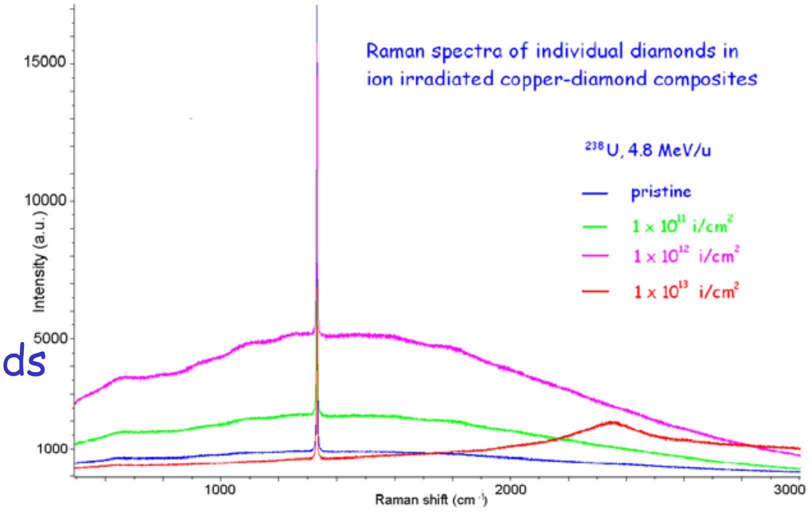
1x10^{13} i/cm^2

5x10^{13} i/cm^2

1.7x10^{14} i/cm^2

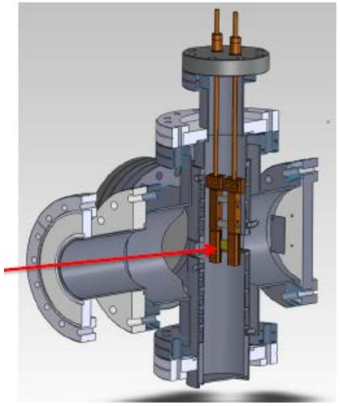


Diamond



- In-situ- SEM during ion irradiation shows:
  - no detachment or cracks at interfaces
  - charge trapping at ion induced defects in diamonds
- Off-line Raman spectroscopy shows:
  - increasing luminescence background due to ion-induced optical active defects

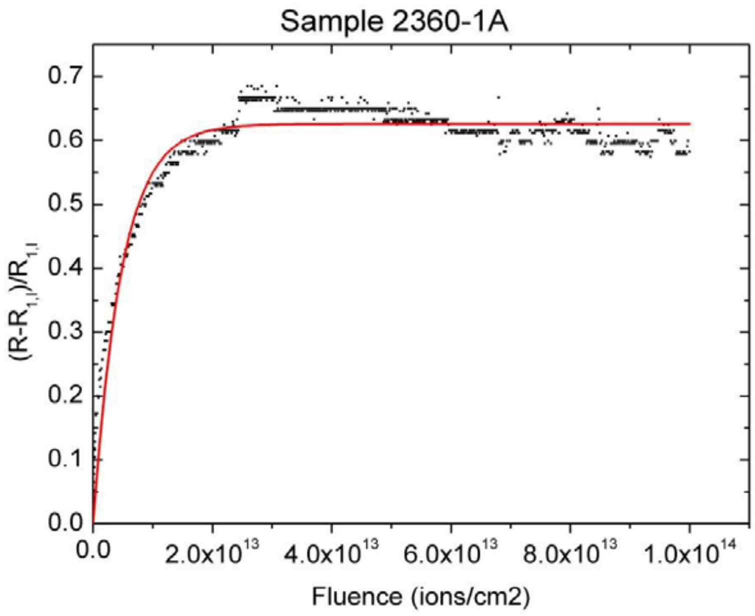
Online measurements of heavy ion-induced electrical resistivity increase of graphite



Collaboration with MSU

Experimental set-up M3 / UNILAC GSI

Irradiation conditions:
ions / energy: ^{197}Au, 8.6 MeV/u
beam intensity: up to 5×10^{10} i/cm^{2}s
dose: up to 10^{15} i/cm^2



Direct impact model fit:

- Poisson Law

$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_{Sat}\left(1-e^{-\sigma_a \Phi}\right)$$

Damage cross section:

$$\sigma_a = 6.0 \times 10^{-14}\ \mathrm{cm}^{-2}$$

Bulk samples irradiation

Cave A
@ SIS

ion beams: 100 – 300 MeV/u
range: mm – cm
scanning system
irradiation in air

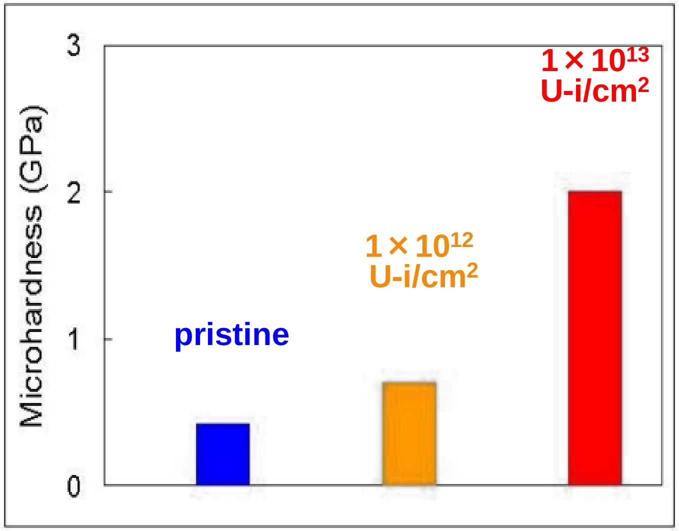
Samples for:
- mechanical testing
- thermal conductivity measurements

Off-line mechanical characterization

Nanoindentation

- -radiation-induced hardening
- Young modulus of irrad. materials

Ex: Hardening of U irradiated graphite



Universal testing machine;

- mechanical strength, fracture toughness, fatigue

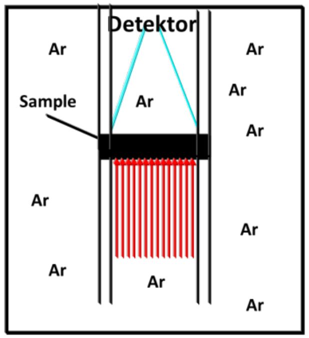
TMA –Thermomechanical Analysis

CTE, creep up to 1650 °C

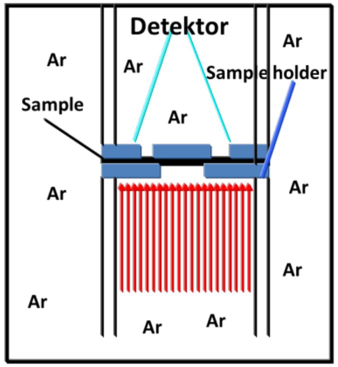
Thermal diffusivity measurements

Thermal diffusivity and Cp up to 2000 °C

measurement in transmission- bulk samples

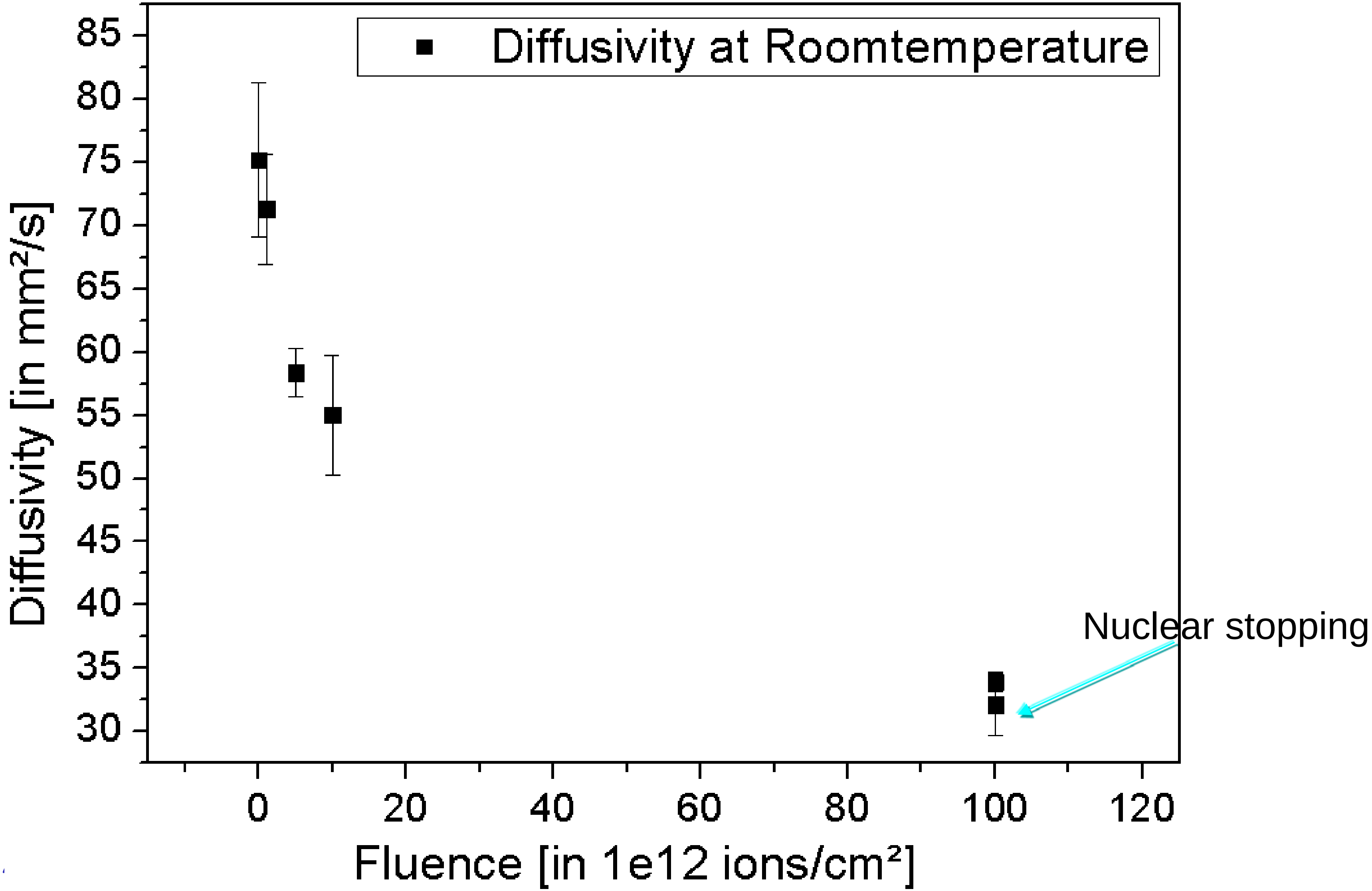


measurement in-plane: thin samples



Thermal diffusivity degradation for Xe irradiated (8,6MeV/u) isotropic graphite

In-plane measurement on 80um thick samples

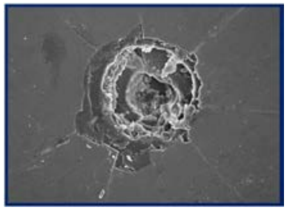


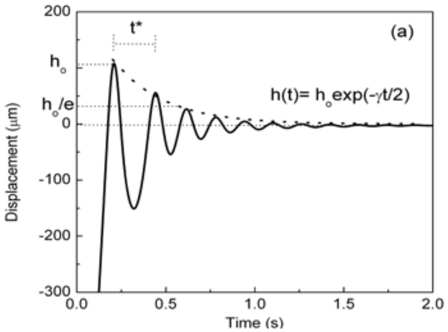
Nuclear stopping

Material testing at fast high energy deposition (& radiation damage accumulation)

Nanoindentation impact

- impact behaviour

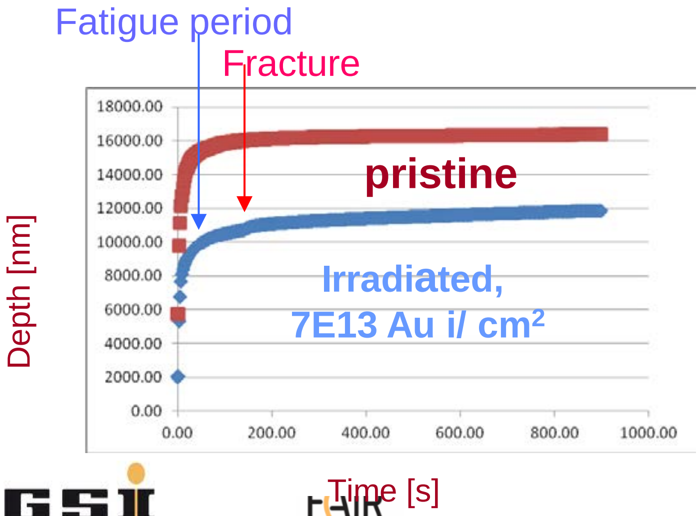




Micromaterials

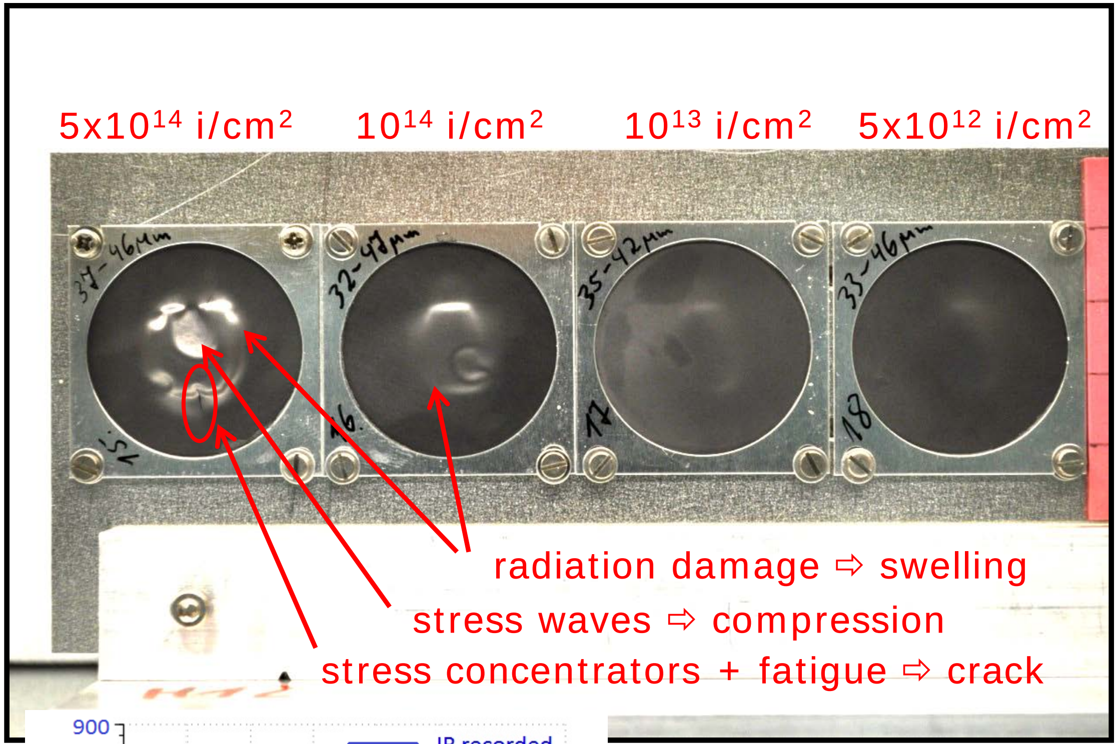
- fatigue behaviour

Ex: fatigue resistance degradation of ion irradiated graphite



Failure of materials exposed to pulsed U beam; thermal camera monitoring

Experiment

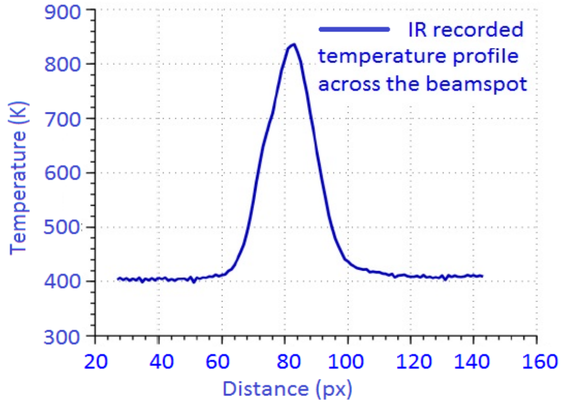


5x10^{14} i/cm^2 10^{14} i/cm^2 10^{13} i/cm^2 5x10^{12} i/cm^2

radiation damage ⇨ swelling

stress waves ⇨ compression

stress concentrators + fatigue ⇨ crack



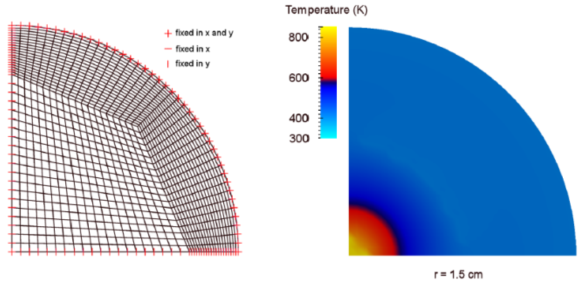
^{238}U, 4,8 MeV/u

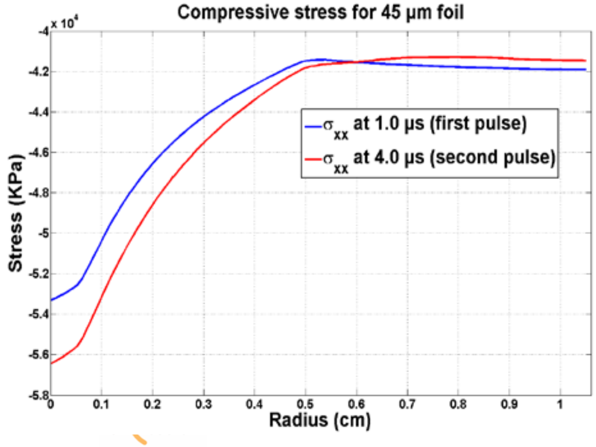
1.5 x10^{10} i/pulse

150 μs, 1 Hz

FEM simulations

Graphite target / Pulse structure	Maximum compressive stress (MPa)	Maximum tensile stress (MPa)
45 μm (single pulse)	-53.3	0.5
45 μm (double pulse)	- 56.4	0.7





Spall strength studies using the PHELIX and CETAL high-power lasers

Laser parameters PHELIX:

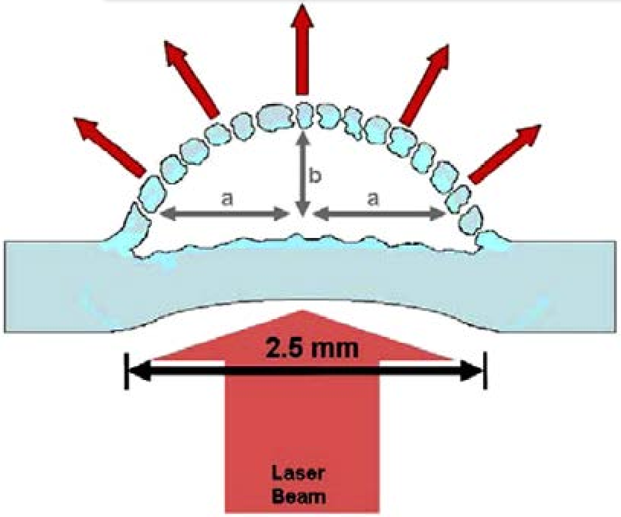
	long pulse	short pulse
Pulse duration:	0.7-20 ns	0.5-20 ps
energy:	0.3-1 kJ	120 J
Max. Intensity:	10^{16} W/cm^2	10^{20} W/cm^2

Laser parameters CETAL:

	short pulse
Pulse duration:	25 fs
energy:	26 J
Max. power:	1 PW

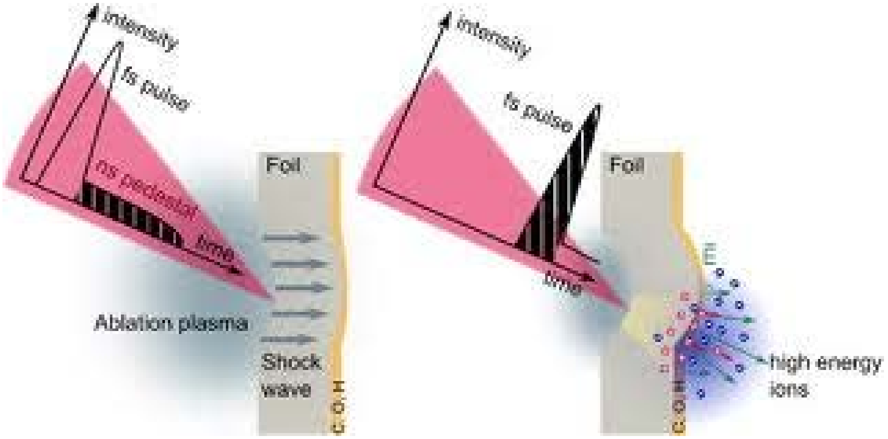
Expansion of the spalling surface in the laser shock experiments

Jarmakani H et al. , Acta Mater (2010)

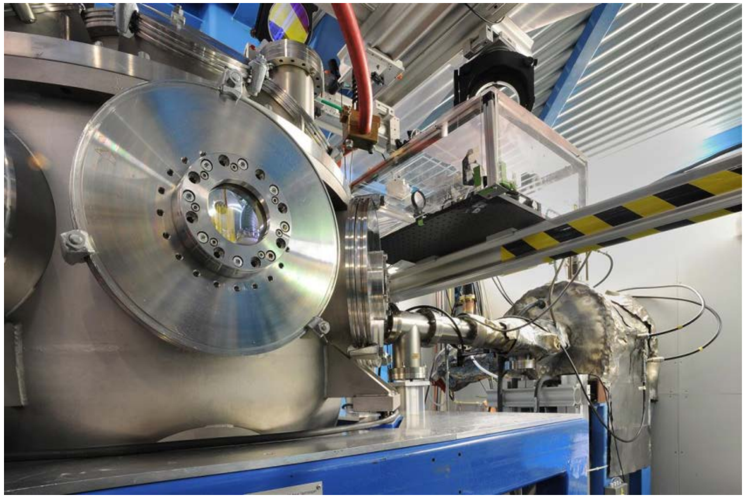


Material response to laser- produced proton beams

Laser proton acceleration:



Laser-based proton beamline at the Z6 experimental area at GSI



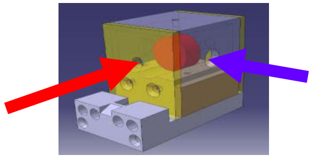
ns pulse length, 10 MeV, 10^9 p/pulse, low repetition rate

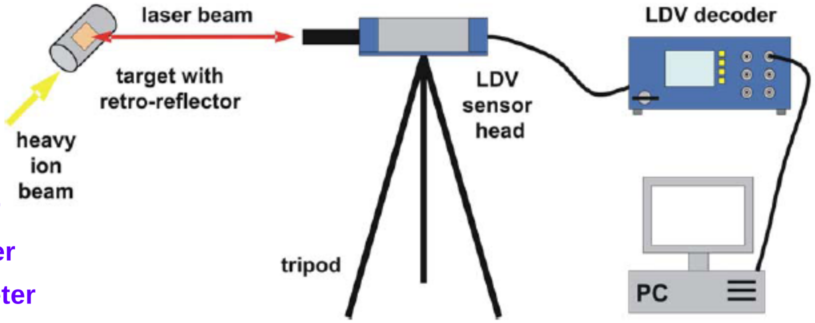
Experimental investigations of pressure waves using fast extracted ion beams at SIS-

Fast-extracted SIS 18 beam pulses:

$N \leq 4 \cdot 10^9$ ^{238}U/pulse, Beam spot size: $\sigma_x = \sigma_y \approx 0.38$ mm

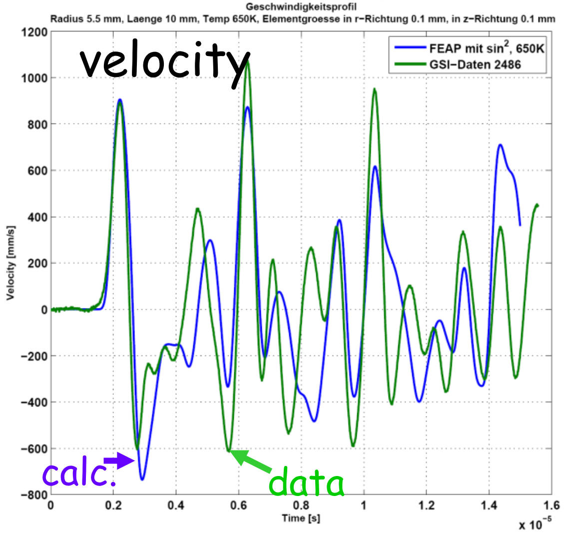
Gaussian time distribution: FWHM ≈ 300 ns

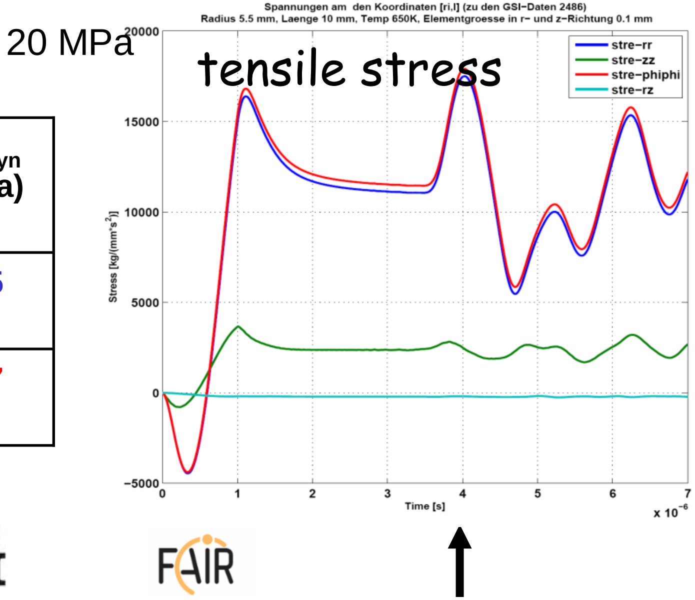




Experiment in collaboration with R. Wilfinger (CERN)

C. Plate, R. Mueller *et al.* (TU Darmstadt)





Exp. case	Beam energy (MeV/U)	Beam intens. (1/pulse)	ΔE/M (kJ/g)	ΔT (K)	ΔP_{static} (MPa)	ΔP_{Dyn} (MPa)
Exp.at SIS18	350	2.40×10^9	1.0	650	31	25
Foreseen at SIS 100	1000	5.0×10^{11}	0.96	580	30	37

Foreseen working plan EuCARD 2

- Irradiation at high energy: 2014 (shutdown from 2015)
- Irradiation at low energy: start mid february 2014 ends July 2014 (not known if beam will be available after 2015)

➡ sample planning with RHP Technology
and Brevetti Bizz
Spall experiments with high power lasers:
end of 2014-2016

- Experiments with Laser generated proton beams: 2015-2016
- Postirradiation characterization and off-line experiments: 2015-2017
- Activities at GSI on modelling of material response in dynamic experiments to start in 2015