OVERVIEW OF EUCARD ACCELERATOR AND MATERIAL RESEARCH AT GSI*

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Abstract

EuCARD is a joined accelerator R&D initiative funded by the EU. Within this program, GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt is performing R&D on materials for accelerators and collimators in workpackage 8 (ColMat). GSI covers prototyping and testing of a cryogenic ion catcher for FAIR's main synchrotron SIS100, simulations and studies on activation of accelerator components e.g. halo collimators as well as irradiation experiments on materials foreseen to be used in FAIR accelerators and the LHC upgrade program. Carbon-carbon composites, silicon carbide and copper-diamond composite samples have been irradiated with heavy ions at various GSI beamlines and their radiation induced property changes were characterized. Numerical simulations on the possible damage by LHC and SPS beams to different targets have been performed. Simulations and modelling of activation and long term radiation induced damage to accelerator components have started. A prototype ion catcher has been built and first experiments have been performed in 2011.
New collaborations with other institutes and industry participating in the EuCARD framework have been established and findings of the joined R&D effort influence decisions in the FAIR project and LHC upgrade. This work offers an overview and points out highlights of the GSI's ColMat activities which are not separately presented within other contributions to this proceedings.

ION INDUCED DAMAGE IN MATERIALS FOR LHC COLLIMATORS JAW

To study radiation-induced dimensional changes and degradation of thermo-mechanical properties, graphite and AC 150 carbon-carbon composite samples were irradiated with heavy and light ions. The irradiation experiments were performed at energies of 11.1 MeV/u, with GSI the UNILAC accelerator at GSI. Similar studies have been started on new candidate materials such as diamond-metal composites. Depending on the specific modifications and functional properties, the most suitable material will be selected for the construction of collimators to be used for FAIR and the LHC upgrade.

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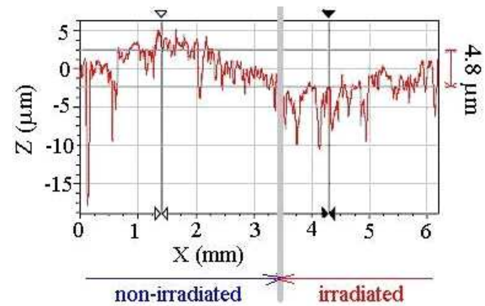

Figure 1: Profilometer scan across the pristine-irradiated border of a AC150 carbon-carbon composite sample, exposed to $1{\cdot}10^{13}$ ^{238}U ions/cm^2, 11.1 MeV/u, showing out-of-plane contraction of irradiated part.

Carbon Fiber-Carbon Composite (CFC)

Dimensional changes of AC 150 grade carbon fiber-carbon composite (CFC) exposed to swift heavy ions were studied by profilometry. A diamond tip is scanned across the interface between irradiated and masked non-irradiated interface. Profilometry of CFC irradiated samples are performed on samples cut along two perpendicular orientations of the fibers. Ion-irradiated CFCs are shrinking along the ion beam direction. This behavior shows that the dimensional change contribution is dominated by the fibers. The graphitic matrix swells on the ion beam direction due to the evolution of the irradiated material towards glassy carbon, which has a lower density (≈ 1.5 g/cm^3 [1]). This effect is specific for ion irradiation, and scales with the linear energy-loss. The fibers are swelling along the radius and are contracting along the axis. Fibers are consisting of coaxial disposed planes, in case of PAN (Polyacrylonitrile) derived fibers. For pitch derived fibers the arrangement of graphitic planes is more complex, but the axis of the planes is always perpendicular to the axis of the fibers. PAN derived fibers are more sensitive to radiation induced damage than pitch derived ones. The radiation-induced shrinking of our CFC material is dominated by fiber axial shrinking (graphitic in-plane contraction that tends to heal vacancies produced by irradiation). The swelling of the fibers is accommodated by the porosity within the graphitic matrix and at the fiber matrix interfaces. The behavior differs along the two cutting directions of the CFC material due to different types of fibers and weaving for this two directions. The strongest contraction effect takes place along the well oriented fibers seen on the "in plan"-cut micrograph, reaching ≈ 4-5 μm (see Fig. 1).

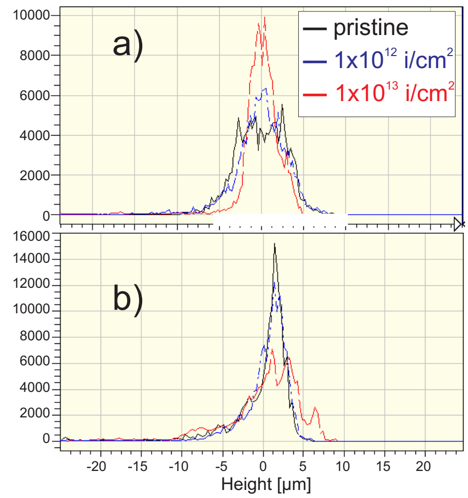

Figure 2: Histograms of roughness for profilometer mappings on the irradiated surface of two different AC 150 C-C composite samples cut along perpendicular orientations of the fibers and exposed to $1{\cdot}10^{13}$ ^{238}U ions/cm^2, 11.1 MeV/u, different fluences: a) in-plane, b) axial.

The histograms of roughness distribution of the two type of CFC surfaces exposed to heavy ions describe statistically the anisotropic changes along the two different directions. The in-plane surface is more structured in the pristine sample (having more defined peaks of the histograms corresponding in the positive part to fibers and in the negative to inter-fiber porosity. This is gradually filled-in, due to fiber and matrix swelling during irradiation (the distribution becomes more centered). The behavior is different in the other direction, starting with a more compact weaving of different fibers and you gradually "mill" them with the ion beam and create more porosity with a broad distribution. The effects are becoming stronger for a critical fluence corresponding to ion tracks overlapping $1{\cdot}10^{13}$ ions/cm^2 for the heavy ions case as illustrated in Fig. 2. One would also expect strong stress and delamination at the fiber-matrix interface due to different behavior with the accumulated dose (swelling- matrix, contraction-fiber). This is sometimes observed in SEM investigations of high fluence irradiated samples.

The values for the phonon mean free path were calculated from the Raman indices of first and second order Raman spectra. Raman spectra recording was performed using a LabRam HR800 UV spectrometer (Horiba Jobin Yvon) equipped with a He-Ne laser of 10 mW power, at an excitation wavelength of 632.82 nm. The depth evolution of the phonon mean free path is correlated to the degradation of thermal conductivity of the CFC's due to ion irradiation. The spectra were taken on the cross-section of the ^{238}U-irradiated CFC sample, along the ion beam direction, starting from the surface, going through the region dominated by nuclear stopping to the end of the ion range and finishing with the non-irradiated material (ions are stopped in the sample). The spectra are always taken on the same

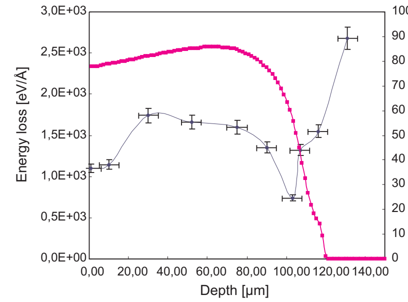

Figure 3: Depth evolution of the phonon mean free path (λ) along the ion trajectory, for carbon fibers in AC150 carbon-carbon composite sample, exposed to $1{\cdot}10^{13}$ ^{238}U ions/cm^2, 11.1 MeV/u. The minimum value for λ corresponds to the elastic collision domain.

type of fiber, as the fibers are the one governing the thermal conductivity of the CFC. On the same graph the total energy loss of the U-ions, calculated with SRIM 2010 code is represented. One could comment that phonon mean free path (and thermal conductivity) is reduced in both mechanism of ion stopping, the reduction being more efficient in the volume where elastic collisions are the dominant damaging mechanism, but non-negligible in the electronic-loss part (Fig.3). The shift between the minimum in the phonon mean free path and maximum of the nuclear energy loss are attributed to SRIM code errors of 10 % and errors in measurements of the distance from the surface of the sample. One could also see that surface is always more sensitive to radiation damage.

Diamond-Copper Composites

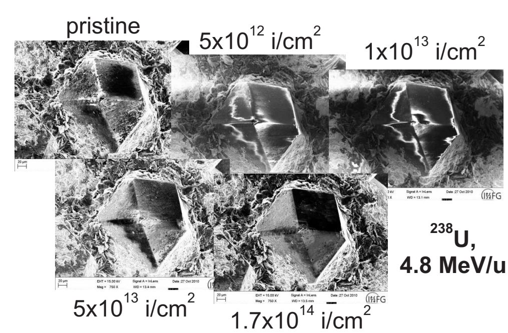

Figure 4: Sequence of in-situ SEM micrographs of a diamond on the surface of a diamond-copper composite sample, exposed to increasing flunces of ^{238}U ions, with an Energy of 4.8 MeV/u

An in-situ experiment was performed at GSI's new M-branch: SEM monitoring of composite behavior during irradiation with ^{238}U ions, up to a fluence of $1.7{\cdot}10^{14}$ i/cm^2. A set of different sites at matrix-diamond interfaces and on the diamonds themselves has been chosen. The samples were irradiated within the SEM with different fluence steps, then rotated to recover the exact position of the investigated sites. Micrographs with the secondary electron detector and in-lens detector were taken at different fluences for the same positions, with magnifications of 750, 7000 and 70000. Crack formation was or diamond detachment at the diamond-matrix interfaces was not observed. The evolution of the diamonds charging behavior with fluence suggests that charge trapping defects are formed within the diamond by irradiation. This charging is present up to $5{\cdot}10^{12}$ ions/cm^2 and quenches-off above 10^{13} ions/cm^2 (Fig. 4).

COLLIMATION AND RADIATION STUDIES

Study on Halo Collimation of Protons in SIS100

For the halo collimation of the proton beam in SIS100 we propose to use a two-stage system which consists of: a) primary collimator (a thin foil) which acts as a scatterer of the halo particles and b) secondary collimators (bulky blocks) located downstream the primary collimator, which are necessary to intercept the scattered particles [2]. For accommodation of the collimation system, vacuum chambers sector 1 of SIS100 have been chosen (see Fig. 5).

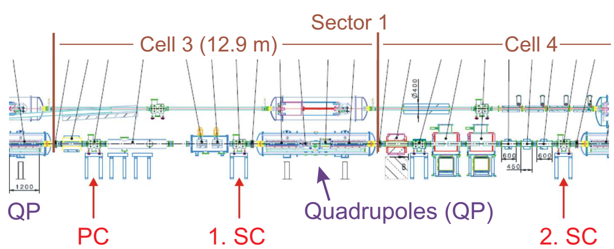

Figure 5: Position of proton collimation system sector 1 of the SIS100 lattice. PC denotes the primary collimator, 1.SC and 2.SC denote the 1st and 2nd secondary collimator, respectively.

The efficiency of the collimation system depends on various parameters such as: phase advances between the collimators, position of the collimators in the lattice, scattering on the primary collimator, retraction distance and number of the secondary collimators. The efficiency of the collimation system can reach over 90% by optimizing these parameters which is actually progressing.

Halo Collimation of $^{238}U^{28+}$ Ions in SIS100

The concept of $^{238}U^{28+}$ ion collimation is based on their charge exchange using a stripping foil. Previous studies showed that most of the uranium ions lost in the process of slow extraction are intercepted with two quadrupoles and the collimator between them [3, 4]. These two quadrupoles originally designed superconducting were changed to warm magnets. This fact can be utilized also for the halo collimation of the $^{238}U^{28+}$ ion beams. The stripping foil is localized in front of the quadrupole doublet and stripped uranium ions are then dumped in the chamber of the warm quadrupoles.

Residual Activity Induced in Collimator Materials with Heavy Ions

Graphite samples were irradiated with 500 MeV/u ^{181}Ta ions and are investigated using gamma-ray spectroscopy. The samples were irradiated in the stacked-disc geometry (see Fig. 6). The tasks of the study are: (1) to identify the radioactive isotopes with dominating contribution to the residual activity and to calculate the activities, (2) to measure depth-profiles of residual activity of induced isotopes mainly fragments of the primary ions and (3) to measure thermal conductivity of the samples after heavy-ion irradiation. Processing of gamma spectra of the samples is now in progress. Other irradiation experiments of graphite samples with uranium ions are planned.

Figure 6: Stack of the graphite discs irradiated with Tantalum ions.

OTHER COLMAT TOPICS AT GSI

The cryogenic catcher prototype for FAIR has been designed and constructed and the first results are presented within these proceedings [5].

The latest results of the simulations for accidental beam loss of LHC beam is presented within these proceedings [6].

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