Minutes of 43rd Collimation Upgrade Specification Meeting

Participants: A. Bertarelli (AB), R. Bruce (RB), F. Carra (FC), M. Calviani (MC), M. Garlasche (MG), P. Gradassi (PG), J. Guardia (JG), A. Lechner (AL), N. Mariani (NMa), D. Mirarchi (DM), E. Quaranta (EQ), V. Raginel (VR), S. Redaelli (SR) (chairman), A. Rossi (ARo), R. Rossi (RR), A. Ryazanov (AR), N. Shetty (NS), G. Valentino (GV) (scientific secretary).
Remote: T. Markiewicz (TM), N. Mokhov (NM),

Indico event here.

1 Investigations of fast proton irradiation effects on Mo-diamond collimator materials for LHC at NRC "Kurchatov Institute" and comparison with the results for Co-diamond materials (A. Ryazanov)

Slides are available here.

1.1 Summary of the presentation

AR presented the cyclotron operation at the NRC "Kurchatov Institute", which is capable of transporting beams of protons, helium ions, carbon ions and oxygen ions at energies in the range of 35 MeV to 120 MeV. These type of beams are useful for irradiating materials composed of oxygen and carbon.

SR clarified that the materials being tested are not the latest ones that are now being considered as candidates for future collimators, as the contract was established in 2011, but AR is reporting on the studies on other materials, and then a discussion is needed to see if the current candidates for materials for future collimators will also be studied.

The microstructures of Mo-diamond and Cu-diamond sample surfaces under different magnifications were presented. AR commented that the precipitate sizes are different for the two samples, and this affects the irradiation results.

AR commented that the value used to explain the effects of irradiation is DPA (displacement per atom). A model of the point radiation damage accumulation in Mo-Diamond and Cu-Diamond materials, as irradiated by 30 MeV protons, was developed. AR commented that these materials are not monolithic or alloys, but are composed of precipitates. The system is composed of sandwich-type layers of alternating diamond and copper or molybdenum-copper. The sizes of the precipitates of diamond vary from 100 μm to 130 μm, while those of copper vary from 50 μm to 65 μm. AB asked why there is a difference in the precipitate sizes. AR replied that this comes for a statistical difference in the material samples.

Two models for radiation damage were developed, one based on a multilayer system, and the other based on the average density of the precipitates. The multilayer model is more convenient, as the precipitates can be separated, and the DPA level can be determined for a given distance.

AR presented the radiation damage profiles from 5 MeV protons for the layered CuCD structure for two layer configurations. The DPA for copper was found to be 5.5×10^{-3}, while the DPA for diamond was found to be 2×10^{-3} and 6.6×10^{-4} respectively in the two configurations.

Displacement damage profiles in copper-diamond and molybdenum-copper diamond irradiated by 30 MeV protons were calculated for lengths from 0 to 2.4 mm. NM asked why there are factor 2 peaks in the profile for copper-diamond. AR replied that these come from Montecarlo statistics.

For the penetration depth calculation, the two models (multi-layer and averaged density) give similar results, while for the DPA calculation, there is a energy-dependent difference. Radiation damage profiles for carbon ions with energy from 26 to 80 MeV in copper and diamond were also presented. The radiation dose was 1×10^{17} - 1×10^{17} ions/cm^2. The DPA decreases with energy and with dose, with values ranging from 0.76 - 2.78 dpa (copper, 1×10^{17} ions/cm^2), 7.6 - 27.8 dpa (copper, 1×10^{18} ions/cm^2), 0.04 - 0.15 dpa (diamond, 1×10^{17} ions/cm^2), 0.4 - 1.5 dpa (diamond, 1×10^{18} ions/cm^2). Hence, the damage levels in diamond materials are approximately an order of magnitude lower than that of copper and molybdenum-copper alloy. AL commented that the typical dpa level after 1 year of operation on the collimator is not known. AB mentioned that it would be important to establish this value for the results from the irradiation studies to be relevant to the LHC.

The physical and mechanical properties in the Mo-Diamond collimator materials before and after fast proton irradiation at 30 MeV were studied. Properties such as the weight, sizes, hydrostatic density, maximum applied load, obtained maximum stress before rupture and Young's Modulus before and after irradiation were measured for each sample (cylinder and parallelepiped). The change in Young's Modulus in Cu-Diamond materials after irradiation are higher (39%) compared to Mo-Diamond materials (16%).

The thermal expansion coefficient for Cu-Diamond increased by 5-7% after irradiation, while a decrease was measured for Mo-Diamond after irradiation. An increase of 37.7% was found in the electrical resistivity of Mo-Diamond after irradiation, while no increase was recorded in Cu-Diamond materials.

Scanning Electron Microscopy (SEM) was performed for the Mo-Diamond composite using a TITAN 80-300 TEM/STEM operated at 300 kV and equipped with a Cs probe corrector system, energy dispersive X-ray spectrometer, electron energy loss spectrometer and a high angle annular dark field detector. The images were analysed to determine the composition of the sample in terms of diamond and Mo-Cu alloy.

AR presented several suggestions for future work In the framework of EuCARD2, concerning the development of theoretical models and numerical calculations of the effect of fast particles on the behaviour of LHC collimator materials. These include the calculation of radiation damage and temperature distribution profiles, as well as the calculation of shock waves in collimator materials under proton irradiation. SR commented that the first year of EuCARD2 was focused on getting the irradiation tests underway, and a the EuCARD2-WP11 annual meeting will be held in December to organize the work ahead. Focus will be put on the simulations that are needed to interpret the beam tests results from Kurchatov, GSI and BNL. SR recalled that priority is put for the moment on the effect of radiation damage.