ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-TUPSA54

BELA INJECTION COMPLEX FOR SIMULATION EXPERIMENTS

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Abstract

BELA (Based on ECR ion source Linear Accelerator) project is under design in NRC «Kurchatov Institute» – ITEP. Injection complex of the accelerator based on two ion sources is intended for different tasks and has multi-channel transport system. One of the tasks is double beam irradiation for reactor materials radiation resistance analysis. Heavy and light ion beams from ion sources will irradiate a target at the same chamber simultaneously. Simulations were carried out for Fe^{10+} at 3.2 MeV ions. The paper includes description of injection complex layout and results of the ion transport in the target material.

INTRODUCTION

Creation of new high-tech power plants, like fusion reactors, and improving the efficiency and safety of existing nuclear power plants includes the development of new materials that can withstand the extreme radiation, temperature and mechanical loads during operation. For the certification of new materials, a set of appropriate damaging doses is required in conditions close to real operating conditions. Certification of new materials for radiation resistance requires the use of reactor radiation. This takes long time, and, in addition, reactor irradiation leads to high induced radioactivity of the materials, which significantly complicates subsequent studies of the samples. For this reason, methods for express analysis of the radiation resistance of structural materials, such as simulation experiments on the irradiation of materials with accelerated heavy ion beams, are required to conduct pre-certification studies. It is known that heavy ions irradiation initiates a cascade production of structural defects similar to that occurring during reactor irradiation. This method allows to save material and time resources at early stages of material development, and to reject samples with obviously weak characteristics. Currently, simulation experiments are conducted at the HIPr-1 [1] and SIRMAT [2] in the NRC "Kurchatov Institute" – ITEP. Now simulation experiments are carried out with pulsed beams with controlled heating of the target to create conditions as close as possible to real operation conditions of nuclear reactors [3, 4]. Reactor irradiation simulation requires simultaneously damage production and H/He injection. Implanted H/He amount has to be in certain ratio to damage value [5]. In this regard, there is need to create a new facility for simulation experiments based on an ion source which able to generate continuous beams. Multifunctional injection complex of BELA is under development in NRC "Kurchatov institute" - ITEP (Fig. 1). The injection complex based on two ion sources is intended for different tasks and has multichannel transport system. One of the tasks is double irradiation simulation experiments for reactor materials.

In addition, for more realistic reproduction of reactor conditions, helium and hydrogen ions will be implanted into damaged region by the heavy ion beam. This process simulates the accumulation of gas products of nuclear reactions, as well as the introduction of hydrogen isotopes from plasma in fusion reactors. In order to avoid distortion of the simulated radiation damage processes in the experiments with ion beams, it is necessary to minimize the surface effects. Therefore, studies are carried out in the intermediate region between the surface of the irradiated sample and the maximum of the implantation ions profile. Simulation experiments analysis makes on defined depth interval. Upper depth dependences on concentration of implanted ions. Down depth is defined by surface effects. This interval decreases with irradiation dose and the experimental temperature increasing [6].

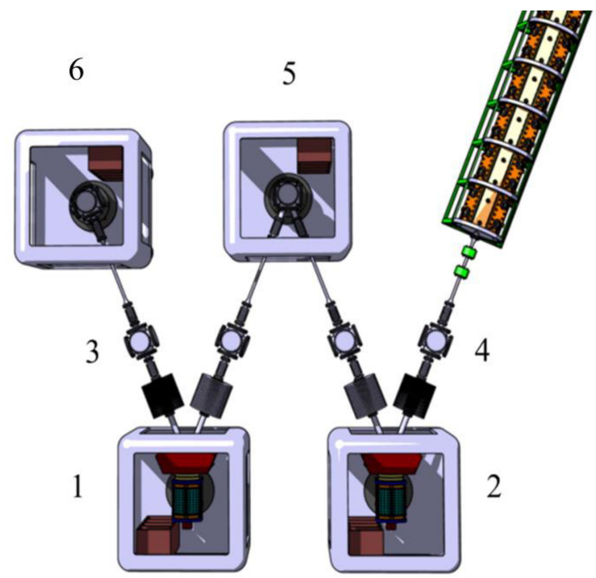

Figure 1: Scheme of the BELA injection complex: 1 – heavy ion source, 2 – light ion source, 3 – transport system, 4 – matching line with RFQ, 5 – double irradiation target chamber, 6 – single irradiation target chamber.

DOUBLE BEAM IRRADIATION

Double beam irradiation scheme is shown on Fig.2. Main beam is Fe^{10+} from ion source (1) line directly irradiates the target and produces lattice damage. H^+/He^+ ions are implanted at specific angle to the surface from the gas ion source (2).

In order to determine the implantation region, ion transport in target material was made using SRIM / TRIM software package.

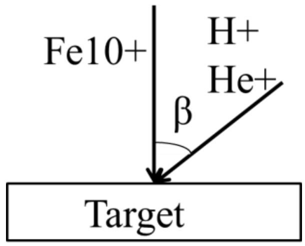

Figure 2: Double beam irradiation scheme.

Modern ECR sources able to generate high-charge ion beams and provide stable operation of continuous Fe^{10+} ions beam. The maximum accelerating voltage, which is technically achievable on the developed system is 320 kV and corresponds to 3.2 MeV energy for Fe^{10+} ions. Fig.3 includes damage and implanted ions profiles for Fe ions at 3.2 MeV. Highlighted region corresponds to the preferable depth for H/He ions implantation. The results of the simulation are shown in Fig. 3.

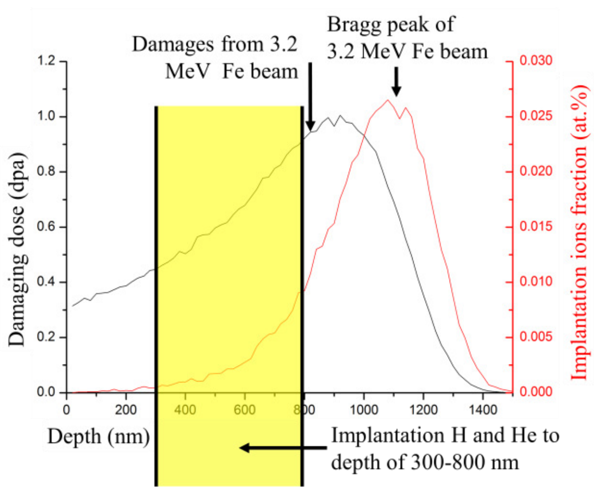

Figure 3: SRIM/TRIM simulation for 3.2 MeV Fe ion irradiation of iron material. Damage dose (dpa) and implanted ions fraction (atomic %) profiles are shown. Highlighted zone (300-500nm) shows preferable depth for the H/He ions implantation.

Hydrogen and helium ions transport in target material for different angles of beam incidence and ion energies was calculated. It was made to determine optimal angle and energy for experiment with different ions. There are H/He irradiation angle limitations. Minimal angle is determined by beamline and target chamber (5) design, maximum angle cannot be more than 60˚ (due to target surface diffusion effect under ion beam irradiation). At the same time, we have limitations for ion beam energy. It depends on minimum voltage for beam extraction from ion source and maximum voltage of high voltage platform. Hydrogen and helium ions behavior in target material at same energy and irradiation angle is different. Beam transport system of injection complex will not movable. It means that the irradiation angle has to be the same for both ion beams. The main task is to determine configuration (angle/energy) for H and He irradiation realization.

CONCLUSION

Double beam irradiation simulation experiments for reactor materials resistance investigation is under development in NRC "Kurchatov institute" – ITEP. It is planned to realize simultaneous irradiation of one target by two ion beams from different ion sources of multifunctional injection complex of BELA. Main beam is Fe^{10+} at 3.2 MeV. Implantation region is 300-500 nm for iron target. Second beams are H^+ or He^+. The next step is irradiation configuration (angle) and conditions (energy) determination for second beams.

ACKNOWLEDGEMENTS

The work was supported by Russian Science Foundation (17-19-01696).

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