LEGIS FACILITY FOR STUDY OF REACTOR STEELS RADIATION RESISTANCE

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Abstract

Considerable efforts have been drawn to adapt heavy ion beams imitation experiments for investigation of radiation stability of materials in nuclear industry, mainly structural materials - steels. Formation of defect structure in the steel using the neutron flow from the nuclear reactors is fraught with many difficulties such as a long-term session of exposure and induced radioactivity in the irradiated samples. Heavy ions instead could provide a versatile tool to induce a precise damage in material under controlled condition. The LEGnaro ECR Ion Source (LEGIS) installed on a high voltage platform (up to 300 kV) allows for the unique possibility of a program for reactor steels investigation by several heavy ion beams. The sample irradiation up to hundreds of dpa (displacement-per-atom) in less than an operation day can be provided by beams of different ions ranging from hydrogen to the iron with different energies. The investigation program and details of experimental facility are presented and discussed in the following.

INTRODUCTION

Nowaday, due to the active development of nuclear power engineering, an actual issue is the investigation of new structural materials for the active zone of nuclear reactors. The exploitation properties degradation of reactor materials is mainly initiated by local structure faults that appear under the influence of high energy particles. Microstructure alterations in materials can be observed both at the grain scale and at the atomic level. Examples of negative macroscopic consequences of these processes are irradiation swelling, embrittlement, irradiation induced growth, and a number of other changes in material properties (see, for instance, [1, 2]).

To characterize structural materials and evaluate their residual operation period, accumulation of corresponding damaging doses under conditions close to real ones is required. It takes too much time and it is not always justified. For example, the accumulation of a dose of ~100 dpa (displacement-per-atom) upon neutron irradiation is achieved for several years even in fast fission reactors. An accelerator-based neutron source is under developing in framework of IFMIF project. It aims at constructing quite an intense (about 10^{17} s^{-1}) 14 MeV neutron source facility, in order to test materials which are foreseen to be employed, as critical components in the future fusion reactors. But even after the IFMIF facility starts operation the test procedure will take significant amount of time and, besides, neutron irradiation leads to a high induced radiation activity of materials, which significantly complicates further investigations.

In structural materials for nuclear reactors, radiation defects are formed, first of all, due to elastic collisions with neutrons. They are generated non uniformly, in cascades of atom–atom collisions.. A neutron with energy of 1 MeV transfers about 70 keV to a primary knocked on atom (PKA) of iron, which is the main chemical element of steels. It is assumed that a PKA with an energy more than 50 keV creates subcascades with an average energy of about 20–30 keV. Low energy ions can simulate PKAs similar to those formed upon neutron reactor irradiation and, correspondently, can simulate cascades that are typical of neutron irradiation. Therefore, over a long period of time, there have been developed methods of express analysis of materials (imitation experiments) with the use of ion beams [3–10].

The LEGnaro ECR Ion Source (LEGIS) installed on a 300 kV High Voltage Platform (HVP) enables the allows for the possibility of a program for reactor steels investigation by several heavy ion beams. The sample irradiation up to hundreds of dpa in less than an operation day can be provided by beams of different ions ranging from hydrogen to the iron with different energies. The continuous beam generated by an ECR source provides many advantages for the imitation experiments. First of all it allows controlling the heating of the samples. Therefore the temperature dependence for irradiation swelling and embrittlement can be investigated in temperature range typical for fusion and fission reactors. Since beams from an ECR can be widely varied in intensities, in addition to investigation of defect generation dependence on the dose, the investigation of the dose accumulation velocity that influence on the defect generation can be carried out as well. Even if it is impossible now to provide at the existing lay-out the simultaneous irradiation of samples by two beams (iron and hydrogen or helium), it is possible to provide mix irradiation by those beams just by selecting the different ion by means of a bending dipole without stopping the ECR operation.

Therefore the developing of imitation experiments with the LEGIS source at LNL provides the good experimental base for material radiation resistance investigation. Those investigations, which are under developing in collaboration with ITEP and MEPhI (Moscow) will be the first step (so called express-analysis) for materials developed for future reactors before their tests at the IFMIF-EVEDA facility.

The experimental lay-out including the target assembly as well as the beam dynamics simulation throughout of

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LEGIS High Voltage Platform (HVP) to the irradiated samples are presented and discussed.

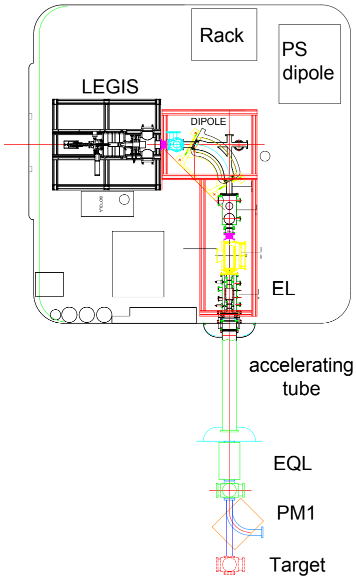

Figure 1: Experimental lay-out.

EXPERIMENTAL LAY-OUT

The experimental lay-out is shown in **Figure 1**. It is an injector for PIAVE superconducting RFQ in LNL-INFN. It is based on the ECR ion source LEGIS (LEGnaro Ion Source - Figure 2) installed at the 300 kV High Voltage Platform (HVP - Figure 3).

LEGIS, High Voltage Platform, Transport Channel

LEGIS is a SUPERNANOGAN type ECR ion source built by Pantechnik for LNL. It provides beams of different materials to be injected in the following SC RFQ PIAVE working as injector for the SC linac ALPI [13].. It is expected that it will provide the beam of Fe^{10+} with an intensityof at least 1 μA. Such beam, accelerated by 200 – 300 kV in accelerating tube, will induce on the target the integral dose of 10^{15} particles/cm^2 in less than half of hour, corresponding to few dpa. The beam with

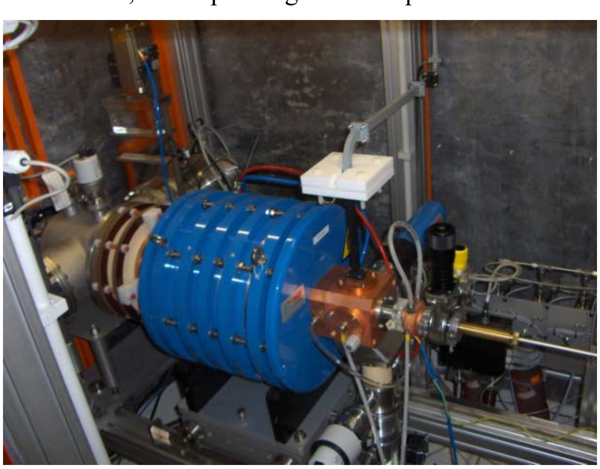
Figure 2: LEGnaro ECR Ion Source LEGIS.


Figure 3: 400 kV high voltage platform, accelerating tube, electrostatic quadrupoles and PM1.

current 10 μA will provide the dose of 10^{18} particles/cm^2 during two days of ion source operation. That dose overcome maximum requested dpa generation. Now Fe ion beam generation by the MIVOC technique is under preparation. We plan to use Ferrocene. Additional advantage of the Ferrocene is the high part of hydrogen ions in the same beam. Therefore the hydrogen beam can be delivered to the target by simply tuning the bending dipole as well as the energy to provide the same depth of implantation for both hydrogen and iron ions.

Focusing elements are located at the input and output of accelerating tube. to ensure beam matching. The line ends with a diagnostic box called PM1 and a bending dipole. The 0° port of this dipole will be used to install the target. The electrostatic triplet at the AT output enables the beam matching with target assembly as it will be shown below.

Target

Target assembly is under developing now. It has to provide the following experimental condition –

i) the vacuum should be better then 10^{-7} mB. It is necessary both to minimize the residual gas atoms insertion into the samples under ion beam bombardment


Figure 4: Samples holder.

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and to keep high vacuum in PIAVE transport channel

ii) the samples heating system has to provide the stable samples temperature during the irradiation. The temperature range is from room temperature to 700°C. Temperature stability during irradiation should be better than ±2°C The target holder will be similar to the one developed for experiments in ITEP and shown in **Figure 4**. Seven samples with diameter of 3 mm can be irradiated during one beam session. They are mounted inside the removable sandwich installed at the cooper holder. Cooper holder has axial hole for heating element and several holes for thermocouple detectors. As it was shoun during experiments in ITEP, using the PID regulator such holder construction provides the samples smooth heating to the required temperature as well as the stability of that temperature within ±1°C. To avoid the heating of target assembly vacuum tank, the tank is designed with water cooling channel. Required heat gradient between sample holder and vacuum tank is provided by the two stainless stars shown in the figure. The dimensions of all elements both for holder and stars and tank were defined by the simulation with COMSOL code [11].

Beam Simulation

The beam dynamics simulation after beam selection to the target assembly was carried out by the TraceWin code [12]. Both transversal emittances and the Twiss parameters for initial beam are shown in **Figure 5** Transport line includes several drift gaps, two electrostatic lenses, accelerating tube and electrostatic quadrupole triplet. The channel parameters were optimized to form the beam spot at the point of samples location with rather uniform distribution inside the diameter of 10 mm. The simulation was carried out with "ideal" fields into all focussing elements. As one can see in figure the beam can be transported along all channel without losses and provide the required spot at the samples surfaces. Moreover the beam is convergent in both planes. Therefore it is possible to change the beam density at the samples by the last triplet tuning only keeping all other parameters of beam line stable.

CONCLUSION

The LEGnaro ECR Ion Source (LEGIS) installed on the 300 kV High Voltage Platform (HVP) allows for the unique possibility of a program for reactor steels investigation by several heavy ion beams. The imitation experiments for material irradiation resistance investigation in collaboration with ITEP and MEPhI (Moscow) are now under preparation. The beam dynamics simulation demonstrated the possibility of Fe10+ ion beam transportation with necessary parameters to the target without losses.

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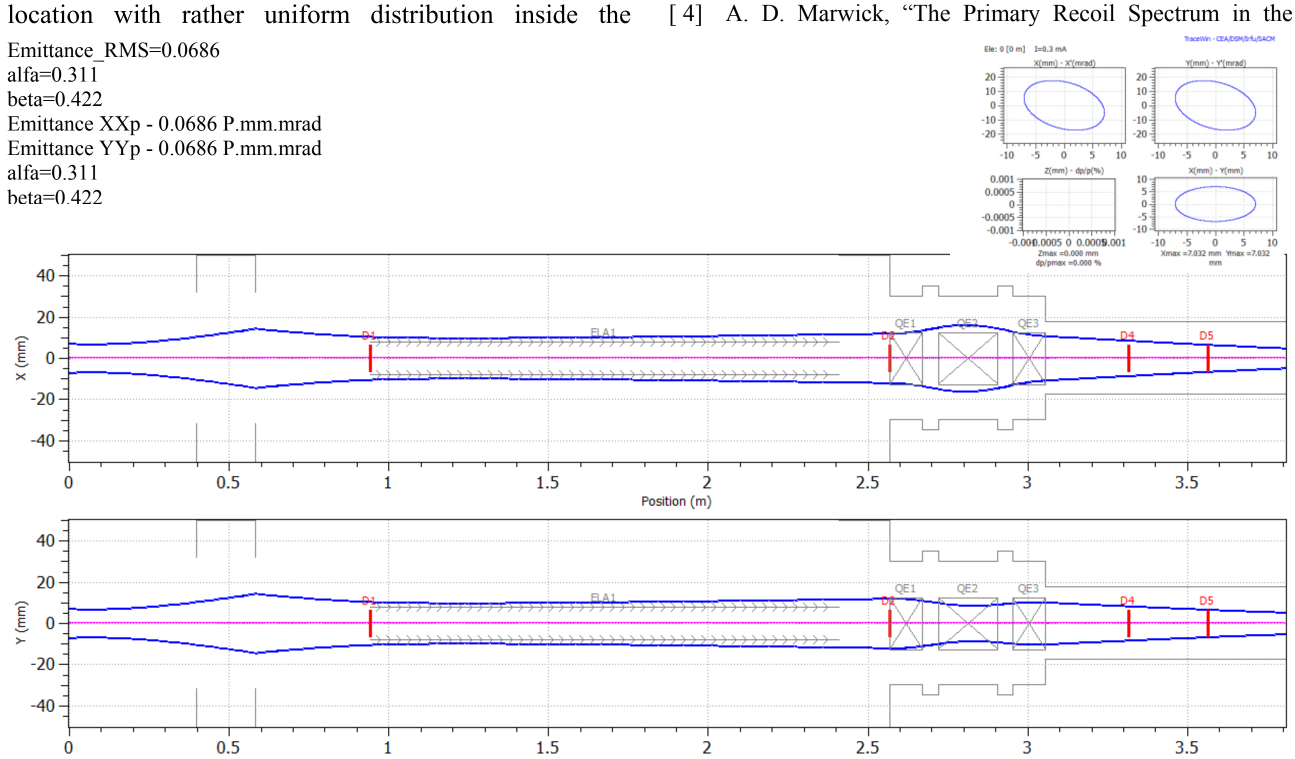

Figure 5: Fe10+ ion beam dynamic simulation. Initial beam parameters and the beam envelope evolution along transport channel.

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