Radiation Damage Analysis on CDG Graphite for SPIRAL 2 Neutron Converter: Preliminary Results

J. Bermudez 1, E. Udup 1,2, L.B. Tecchio 1, L. Maran 1, L. Pranovi 1

1 INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy.
2 Horia Hulubei National Institute of Physics and Engineering, Bucharest, Romania.

INTRODUCTION

On the framework of SPIRAL 2 project, graphite made of natural carbon has been chosen as converter material among several tested materials. The graphite-brand results the most suitable one to produce intense neutron flux under rather severe operation conditions. In SPIRAL 2 a neutron flux of $1\times10^{12} \text{ cm}^{-2}\text{s}^{-1}$ is estimated to induce fission on the UCx target, starting from a primary 40 MeV, 5 mA current (200 kW) deuterons beam [1]. Analysis of the mechanical and physical properties has been carried out over several brands of graphite in order to establish the optimal graphite for the converter [2]. However, still have not been found in literature experimental data reporting deuterons radiation damage produced on graphite under high temperature conditions as those corresponding to the maximum peak power density of 60 kWcm$^{-2}$ of SPIRAL 2. Calculations have shown that a deuteron beam induce a 50 dpa damage per year mainly concentrated in the Bragg region, when considering neutron radiation damage negligible and without take into account annealing. Process like hydrogen/deuterium production and consequently swelling can take place on the converter.

A preliminary calculation suggests that mobility of deuterium in amorphous carbon is much lower than in graphite. Simulations of deuterium diffusivity at 1800°C based on molecular dynamic code REBO show a graphite diffusivity of $10^{-8} \text{ m}^2\text{s}^{-1}$ while diffusivity of amorphous carbon was estimated to be $10^{-10} \text{ m}^2\text{s}^{-1}$. This result correlates the diffusion of deuterium with the material structure. A first approach to the radiation damage analysis over graphite was carried out at CN accelerator of LNL. Structural and superficial analysis of graphite was done to evaluate changes on the structure of the material. The preliminary results of the experiment are presented.

EXPERIMENTAL SET UP

The CN accelerator of LNL may deliver 6 MeV, 4 μA proton beams, with a current density up to about 20 mAcm$^{-2}$. The beam energy used was 5 MeV, proton density was $7.8\times10^{18} \text{ cm}^{-2}$, corresponding to a total number of protons of $1.6\times10^{18}$ and beam spot of 0.2 cm$^2$ area. For this study CDG graphite was employed. The selection of the graphite was made base on the commercial availability. Dimensions of graphite sample were 20x25x3 mm, fixed to a steel disc support allowing the measurement of the current during the irradiation (see figure 1).

![Fig. 1. Scheme of the graphite sample fixed to steel support.](image)

A surface of 20 mm$^2$ on the central part of the sample was irradiated. The calculated damage induced by 6 MeV proton beam after irradiating the graphite sample about 20 hours, is more than 1 dpa. Deformation and changes in the graphite structure were measured by profile-meter, XRD and SEM techniques.

EXPERIMENTAL RESULTS

The profile-meter was used to determine changes on the sample surface. A Veeco Dektak surface analyzer was used to obtain a map of 7x7 mm. The complete region includes the irradiated spot and un-irradiated zones around it. This analysis allows for determining changes on the surface relative to the region un-irradiated and can be observed in the same image. Results are shown in figure 2.

![Fig. 2. Surface profile map of the CDG-graphite irradiated.](image)
The XRD analysis was done on the bulk of CDG sample to evaluate changes on the crystalline structure of graphite. Alternatively was prepared a surface XRD arranging the system for thin films. The analysis was carried out using a XRD Phillips Cu anode at 40 kV and 40 mA. Results are shown in figure 3.

Fig. 3 XRD of CDG graphite. (Top) bulk irradiated and un-irradiated. (Bottom) surface irradiated and unirradiated.

The XRD reveals no differences between irradiated and un-irradiated regions. The crystalline structure evidence the major peak at $2\Phi = 26.36$ corresponding to a $d$ spacing of 3.38103 Å is identical for both cases, bulk and surface analysis. The differences observed on the intensities are the response to lower acquisition when low-angles x-ray beam is used. The main peaks $d$-spacing and their relative intensities are reported in Table 1.

Table 1. Main peaks identified in all XRD patterns.

<table>
<thead>
<tr>
<th>Position $2\Phi$</th>
<th>d-Spacing Å</th>
<th>Relative Intensity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.3608</td>
<td>3.38103</td>
<td>100.00</td>
</tr>
<tr>
<td>42.4019</td>
<td>2.13178</td>
<td>4.82</td>
</tr>
<tr>
<td>44.4831</td>
<td>2.03676</td>
<td>8.08</td>
</tr>
<tr>
<td>54.4523</td>
<td>1.68509</td>
<td>3.93</td>
</tr>
<tr>
<td>77.5039</td>
<td>1.23163</td>
<td>5.07</td>
</tr>
</tbody>
</table>

SEM analysis was also carried out in order to observe the surface morphology of the graphite sample. The results at two different magnifications are presented on figures 4 and 5. The images obtained give no information about variation on the graphite structure. The tests have been performed without finding evidence of significant changes on the structures or surfaces of irradiated and un-irradiated regions.

Fig. 5. SEM analysis images at 100 μm. LEFT: un-irradiated region; RIGHT: Irradiated region.

**DISCUSSION**

The damage caused by 1 dpa radiation level seems to be less than enough to evaluate the SPIRAL 2 radiation conditions and radiation damages over graphite. Moreover, to improve the analysis reliability the use of same radiation particles have been proposed, in our case deuterons for future experiments. This allows the evaluation of penetration depth and energy released on the graphite, which are useful parameters for the choice of graphite with optimal characteristics for neutron converter. Furthermore analyses are already planned to be carried out at ALTO IPN Orsay, using a deuterium beam of 27 MeV, inducing 10 dpa damage.

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[1] F. Varenne; EDMS SP2_DT_831S_I016691_v0.1.