Gamma and Proton Induced Degradation in Ceramics Materials–a Proposal

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Abstract. Ceramic materials will play very important roles in developing fusion reactors, where they will be used under heavy irradiation environments (neutrons, gamma-rays, protons, helium and other ions) for substantial periods for the first time. The programme at the Institute of Atomic Physics in Bucharest forms a part of the on going ceramics programmes to assess the suitability of SiO2 based materials for both diagnostic and remote handling application. The authors' proposal focuses on comparison of the ionization and displacement induced damage (influence on the UV and visible optical transmission properties) and on radiation enhanced hydrogen isotope diffusion in these materials; the work is performed in cooperation with CIEMAT Madrid and SCK/CEN Mol. The irradiation facilities are: IRASM – 200 kCi Co-60 source, minimum 2kGy/h, ethanol chlorine benzene and ESR dosimetry; HVEC 8 MV TANDEM – protons up to 16 MeV and 200 nA; and 600 kV DISKTRON – H isotopes up to 600 keV, tens of microamperes.

1. Introduction

Ceramic materials are anticipated to play very important roles in developing nuclear fusion reactors, where they will be used under heavy irradiation environments (neutrons, gamma-rays, protons, helium and other ions) for substantial periods for the first time [1,2]. Extensive studies have been carried out for several decades on radiation effects of ceramics concerning fundamental aspects [3]; however, we seriously need to understand the effects induced not only by neutrons and alpha particles but also by gamma and proton irradiation.

Traps for hydrogen isotopes would cause a significant increase in the tritium inventory in the plasma-facing components of D-T reactors. Energetic particles (including protons) and gamma rays bombard the materials and produce radiation damage, which would become trapping sites for hydrogen isotopes. There have been many experimental studies [4] on hydrogen trapping in metals by nuclear reaction analysis (NRA), Rutherford backscattering (RBS) or elastic recoil detection analysis (ERDA), but not yet sufficient studies on ceramics. Three key ceramic materials being considered are Al_2O_3, BeO and AlN; while publications dealing with these materials are available, the database is incomplete and uncertainties are large concerning the solubilities, diffusivities, trapping and release of tritium in materials, particularly during irradiation [5].

One puzzle to emerge in the study of insulators for fusion reactor applications is a form of radiation-induced electrical degradation [6,7]. Virtually every aspect of the heating, control and plasma diagnostics relies on the insulator. Degradation occurs much more rapidly when there is displacement damage, ionizing radiation and an electric field (RIED: radiation induced electrical degradation). The puzzle lies especially in the role of the electric field; even small fields (lower than 1 kV/cm) somehow affect damage mechanisms so that large disc-like defects are formed and the resistivity degrades.

Among the important applications of fiber optics envisioned for the near future are light pipes for monitoring tokamak fusion reactor plasma conditions. These applications will make unprecedented demands for hardness against optical attenuation induced by moderate to very high doses of gamma rays and neutrons. In particular, fibers for these tasks will be required to maintain good transmission over the entire visible range (400 – 700 nm) [8-12].We intend to start a general programme on gamma and proton induced degradation in optical transmission materials, including windows and optical fibres. As a first step, we shall concentrate on assessing the suitability of SiO2 based materials for both diagnostic and handling applications.

2. Main Milestones for the Proposal

Our proposal focuses on:

- comparison of the ionization and displacement induced damage in SiO2 based materials and the influence on the UV and visible optical transmission properties
- radiation enhanced hydrogen isotope diffusion in SiO2 based materials

The main characteristics of Bucharest irradiation facilities are:

- IRASM IRRADIATOR: 200 kCi Co-60 “swimming pool” irradiation source, minimum 2 kGy/h with an isotropic dose rate up to 1 Gy/s, ethanol chlorine benzene dosimetry, ionization chamber dosimetry, ESR dosimetry
- HVEC 8 MV FN TANDEM: protons up to 16 MeV and 200 nA, alpha particles up to 21 MeV and 50 nA, O, C, N ions approximately 100 MeV up to 50 nA
- DISKTRON (600 kV, ECR source): hydrogen isotopes up to 600 keV and tens of microamperes

The following main milestones for the project have been agreed for 2000-2001:

- designing a gamma irradiation chamber, acting underwater, allowing various temperatures (20-300 C) on the sample; this involves finding adequate solutions for dosimetry, heating system and UV absorption and radioluminescence apparatuses (including their information transmission systems) acting in a very intense gamma ray field in the water pool of the Co-60 irradiator. To be completed by December 2000.
- designing a high energy proton irradiation chamber, acting in high vacuum, allowing various temperatures on the sample in the presence of irradiation proton beam heating (1 mA x 1MeV = 1 W); this involves finding adequate solutions for dosimetry, heating system and UV absorption and radioluminescence apparatuses working in high vacuum conditions. To be completed by December 2000.
- characterizing the irradiation conditions (dosimetric aspects, radioactivity, emergency situations) for gamma rays and protons. To be completed by December 2000.
- realizing the gamma and proton irradiation chambers at various temperatures. To be completed by March 2001.
- studying the possibility to add, in the previously mentioned irradiation chambers, systems allowing electric fields (10 - 20 V/cm) to be applied on the samples during both gamma and proton irradiation. To be completed by March 2001.
- testing ERDA performance at the Bucharest Van de Graaff TANDEM accelerator for implanted deuterium profile determination on a ceramic sample. To be completed by March 2001.

- testing irradiation performance for the Co-60 irradiator and the TANDEM accelerator on two ceramic samples. To be completed by March 2001.

As a first step, irradiation chambers will be prepared and calibrated to permit SiO2 based optical materials to be irradiated with Co-60 gamma rays and high energy protons (up to 16 MeV) at room temperature. Using the ethanol chlorine benzene, ionization chamber and ESR dosimetry methods, we will determine the gamma ray dose at the irradiation position and its space distribution. The safety analysis will be focused on a future in situ test stand use. Using specific nuclear dosimetry methods (ionization chamber, current integration), we will determine the proton dose and its spatial distribution around the sample position. The safety analysis is directly connected to the estimation of induced radioactivity in irradiated materials and their handling and transport for post-irradiation examination.

The degradation of the optical transmission over the UV and visible range will be determined to compare the role of ionization and displacement damage. The possibility of irradiation at elevated temperature will be examined. Depth profiles will be determined for implanted hydrogen isotopes under different conditions to determine the role of ionizing radiation in the diffusion. The influence of an electric field will also be considered. For hydrogen isotope depth profile the ERDA at the HVEC TANDEM will be used. The work will be carried out in collaboration with CIEMAT Madrid and SCK/CEN Mol in the frame of the EURATOM 5th Framework Programme of the European Union.

The next step will be studies on radiation hardening of various optical fibers by high dose gamma ray irradiation using an in situ test stand at the IRASM facility.

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