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Ion/Electron Induced Luminescence for Radiation Damage Process Interpretation and *In Situ* Material Verification

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Abstract

The Research Centre for Energy, Environment and Technology (CIEMAT), Madrid, Spain, features two installations (2 MeV Van de Graaff electron accelerator and a 60 kV ion implanter) specifically developed for *in situ* material characterization during irradiation, and focused on the study of volume and surface electrical degradation in insulating materials for fusion applications. These installations have been equipped with optical systems which permit electron and ion beam induced luminescence to be measured at the same time as recording the electrical conductivity. Recent results for combined ion-induced luminescence and surface electrical degradation experiments in alumina confirmed a correlation between conductivity changes and evolution of emission bands with irradiation dose. Similar experiments under electron irradiation in silicon carbide have also shown the usefulness of luminescence for material characterization and evaluation of radiation effects.

Keywords: electron accelerator, ion implanter, luminescence, radiation damage

Introduction

One of the main research activities within the Fusion Materials group at CIEMAT (Research Centre for Energy, Environment and Technology), Spanish public research body located in Madrid, is currently the investigation of radiation effects on electrical properties of insulating materials. Numerous systems in fusion devices, including

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plasma heating, diagnostics and remote handling, require the use of insulating elements. Depending on the location, these materials will be subjected to different levels of neutron, gamma, and charged particle fluxes, and will be required to maintain for as long as possible not only their mechanical properties but also the very sensitive physical properties such as electrical conductivity. Expected radiation damage such as Radiation Induced Conductivity (RIC), Radiation Induced Electrical Degradation (RIED), and surface electrical conductivity degradation must be examined for the candidate materials [1-3].

Although simulation of radiation damage through theoretical calculations and models provides valuable information in the prediction of materials behaviour during irradiation at experimentally unattainable dose scales, testing of materials under real radiation conditions is essential in order to establish their operation capabilities. The use of charged particle accelerators for radiation damage investigation is widespread, as a versatile means of reproducing radiation effects under properly controlled conditions of temperature, pressure, and dose rate.

The CIEMAT features two installations specifically developed for *in situ* material characterization during irradiation, where experimental setups are mainly focused on the study of volume and surface electrical degradation: The 2 MeV Van de Graaff electron accelerator, which permits the study of ionizing effects and displacement in the volume, and a 60 kV ion implanter to examine surface effects. The major goal of these facilities is the possibility of in situ and real-time measurements as a function or irradiation dose under different conditions.

Among other effects, the transfer of energy from the incident particle to atomic or molecular electrons in the insulator material may give rise to the emission of light, defined in this text according to excitation source as radioluminescence (RL) for high energy electrons, and ion beam induced luminescence (IBIL) for ions. Consequence of electronic transitions between characteristic energy levels, it provides information about the state of solid lattice structure and defects. Radiation induced material modification including point and extended defects creation, impurity valence changes, or segregation which affect physical properties may cause identifiable changes in luminescence bands, enabling direct and continuous material performance verification during irradiation.

The accelerator and implanter installations have been equipped with optical systems which permit electron and ion beam induced luminescence to be measured at the same time as recording the electrical conductivity. This allows one to observe a correlation between the two processes, considered to be the first step to permit *in situ* monitoring of radiation induced degradation in materials by means of luminescence.

Examples for experiments made in silicon carbide and aluminium oxide which illustrate luminescence potential for this purpose as well as for the characterization and study of ceramic materials for fusion applications, are presented.

1. Installations

1.1. The 2 MV Van de Graaff accelerator (VDG)

The Van de Graaff high voltage generator was acquired in 1953 and was first dedicated to fundamental nuclear physics research activities involving proton, deuterium and He induced reactions. Two decades later, when more recent and higher voltage Van de Graaff accelerators had entered the scene and the 2MV machine could no longer contribute effectively in this field, the installation operation was redefined. Important modifications in the VDG system transformed the installation into the present 2 MV electron accelerator dedicated to the study of radiation effects in materials, becoming the European reference laboratory for fusion research in ceramics insulators with unique experimental systems for in-situ optical absorption and emission measurement, and the study of electrical and dielectric properties (DC to GHz), as well as He and H isotope diffusion.

A simplified experimental scheme is given in Figure 1, where radioluminescence measuring system, including