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Temperature response of several scintillator materials to light ions

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ABSTRACT

Ion beam induced luminescence has been used to study the response of scintillator screens of $Y_2O_3:Eu^{3+}$ (P56) and $SrGa_2S_4:Eu^{2+}$ (TG-Green) when irradiated with light ions (protons, deuterium and helium particles). The absolute efficiency of the samples has been studied as a function of the ion energy (with energies up to 3.5 MeV), the beam current and the operating temperature. The evolution of the scintillator yield with ion fluence has been carried out for all the scintillators to estimate radiation damage. Finally, measurements of the decay time of these materials using a system of pulsed beam accelerated particles have been done. Among the screens under study, the TG-Green is the best suited material, in terms of absolute efficiency, temporal response and degradation with ion dose, for fast-ion loss detectors in fusion devices.

1. Introduction

In plasma fusion devices, fast ion losses caused by different mechanisms (prompt losses, coulomb collisions and MHD activity) represent a twofold problem for the reactor performance. Indeed, on the one hand, they do not contribute to the plasma heating leading to a decrease of the plasma power and, on the other hand, the plasma facing components can be damaged by the impinging particles [1]. The principal diagnostic to obtain information about the wave-particle interaction responsible for the fast ion losses in a magnetic fusion reactor is the scintillator based fast-ion loss detector (FILD) [2]. Based on the concept of the α-particle detector used in TFTR [3], probes are installed in several fusion devices like ASDEX Upgrade (AUG) [4], Joint European Torus (JET) [5], etc. The FILD system acts like a mass spectrometer collimating the incoming ion that reaches the scintillator.

The light produced by lost fast ions striking in the scintillator screen is imaged by a double system (camera + photomultipliers array) capable to provide time resolved measurements of the velocity space of escaping ions. The use of a scintillator material with a very short decay time makes it suitable to follow the frequency of the magnetohydrodynamics fluctuations (ELMs, TAEs, etc) present in fusion plasmas, but absolute measurements of the escaping ions are, however, not available due to the complex dependence of the detector response on the scintillator efficiency with varying temperature. During tokamak operation, heat load at first wall could make FILD operates in a hostile environment. This involves knowing the absolute efficiency in a wide range of temperatures to make them relevant for larger devices and reactors. The behaviour of scintillator material to irradiation with light ions is well reported in the literature at room temperature [6,7] but the absolute characterization of the scintillator response to charged particles at high temperature is not available. In this article, the absolute efficiency at different temperatures, the degradation of the scintillation yield and the characteristic decay time of two different scintillators used in FILD detectors have been carried out. After an introduction given in section 1, the experimental setup is described in section 2, finally the main results are presented in section 3.

2. Experimental setup

2.1. Characterization of scintillator efficiency and degradation in a tandem accelerator

FILD systems are normally equipped with thin scintillator coatings that show a high efficiency to charged particles and low to

Abbreviations: MHD, Magnetohydrodynamics; TFTR, Tokamak Fusion Test Reactor; Elms, Edge-Localized Modes; TAE, Toroidal Alfven Eigenmode; RBS, Rutherford backscattering spectrometry.

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other radiation fluxes present in a tokamak such as neutrons and gammas. The scintillators investigated in this work for ion beam irradiation experiments were selected according to their high efficiency, radiation hardness, heat resistance, fast response, and/or prior use in plasma diagnostics. The TG-Green phosphor (so called by the manufacturer, SRI International, USA) is an Eu doped $SrGa_2S_4:Eu^{2+}$ powder substrate with a density of 3.65 g/cm^3, physical thickness ≈9 μm and presents an emission at 535 nm with a very short decay time ≈490 ns [8] suitable to identify the frequency of the MHD fluctuations [9]. The P56 scintillator is an Eu doped Y_2O_3 powder substrate, manufactured by AST Corporation, England with a physical thickness around 28 μm. Although this material has a high efficiency, its light emission has a long decay time of 2 ms [10]. The characterization of the scintillator response to charged particles has been performed using the 3 MV tandem accelerator of the National Accelerator Centre (CNA) [11]. In order to measure the scintillation properties at different temperatures, a new vacuum chamber with black coating (to avoid reflections on the chamber wall) and equipped with a sample heater (ceramic resistance), a temperature control monitor (thermocouple) to cover the operation temperature range expected in fusion devices and a photonic diagnostic system have been installed at CNA in one dedicated beam line. The samples under study were placed in an electrically isolated holder. Movement of the sample holder was controlled remotely through stepping motors, capable of providing a linear motion in X-Y directions. This permits a fine control of the beam spot positioning as well as the study of several samples without venting the chamber. A collimator located at the entrance of the chamber permits adjusting the size of the ion beam between 1 and 3 mm. The position of the beam was monitored using a videocamera located outside of the chamber. The excitation and simultaneous measurement of the scintillation yield have been made by irradiation at normal incidence with light ions H^+, D^+ and He^{++} with energies between 1 and 3.5 MeV and different temperatures up to 500 °C. Electrons emitted by thermionic effect in the holder at high temperature operations do not allow to measure directly the beam current at the vacuum chamber (Fig. 1). Instead, the incident beam current has been determined using a calibrated beam chopper connected to a digital current integrator (model 439 by Ortec). The beam currents intensity used to irradiate the scintillator were kept constant at around 1–2 nA for the yield determination and 25–30 nA for the degradation tests. During the irradiation experiments, the vacuum pressure has been kept constant at ≈10^{-4}–10^{-5} mbar. The emitted light from the scintillator was collected with a silica optical fiber of 1 mm diameter fixed to a side port of the vacuum chamber and connected to a high sensitive spectrometer, QE65000 (Ocean Optics Inc) which allows to measure the spectra of the scintillator in the range of 200–1100 nm with a spectral resolution ≈1–2 nm. The absolute calibration of the optical system was carried out with a source HL-2000-CAL Tungsten Halogen Calibration Standard light source.

2.2. Characterization of decay time with a beam pulser

The decay time of both scintillators has been experimentally determined at different temperatures using a 1 MeV proton pulsed beam. The light emitted from scintillator has been recorded with a photomultiplier (PMT, Hamamatsu, Model H10721) that converts the photons into electrical pulses. The connection of the PMT with a fast oscilloscope (LeRoy 204MXi-A 2 GHz) (Fig. 2) allows us to study the time evolution of the scintillator response. Different pulse widths and periods according to manufacturer decay time specifications have been used in these tests.

3. Results

3.1. Absolute efficiency of scintillators as a function of the temperature

The ionoluminescence spectra were acquired by the spectrometer exposure time set to 1 s and were normalized by the beam current intensity. The measurements were carried out when the scintillator was stabilized to the operation temperature (±5 °C) and before the light yield started to degrade. Figs. 3 and 4 show the measured spectra for the TG-Green scintillator and P56, respectively, excited with a deuterium beam of 3 MeV for different temperatures. The signals are normalized with respect to the emission at room temperature. For the TG-Green, the light output of the scintillator quickly decreases with the temperature operation. The spectra present a broad peak centered at 535 nm and no shift was observed in the wavelength between RT and 500 °C, indicating that the temperature does not affect the gap energy configuration of the sample. Similar results have been observed for protons and alpha particles. The P56 spectra present different emission bands with the main emission centered at 611 nm. Its light yield also presents a decrease with the temperature for all the bands, but the diminution is less pronounced than for the TG-Green scintillator. It has been found that the quenching mechanism is identical in the most intense bands. In both cases, the absolute yield was calculated by integrating the spectra in the ROI for each scintillator. One important parameter found in this work is the experimental ratio ($\kappa = \varepsilon_T/\varepsilon_{RT}$) between the yield at different temperatures (ε_T) with respect to room temperature (ε_{RT}). It has been proven that, within the energy range explored in this work, the ratio is approximately independent of the energy of the beam but slightly rests on the ion mass. The overall findings for the chosen scintillator are summarized in Table 1 for the TG-Green and in Table 2 for the

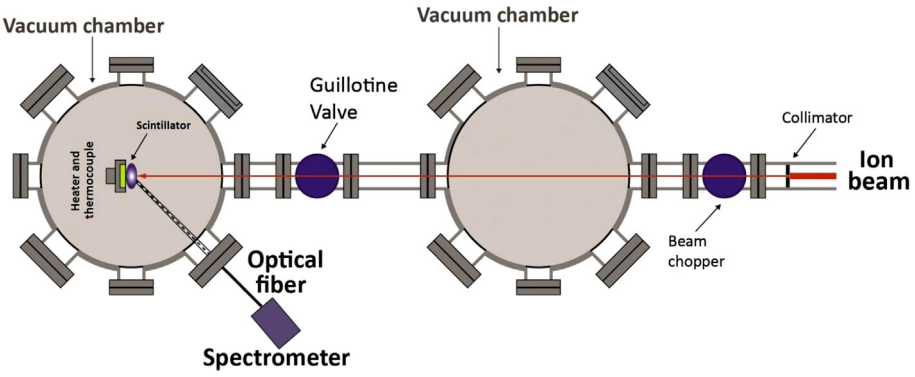

Fig. 1. A schematic diagram of the experimental IBIL (ion beam induced luminescence) set-up at CNA showing the scintillator and the photon detector as well as the incident ion beam and light acquisition systems.