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Development of Ceramic Scintillators for Lost Alpha Measurement on ITER

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Abstract

A new type of ceramic scintillator has been developed for lost alpha measurement on ITER, where severe environments for measurement, such as high temperature, high neutron/gamma flux and difficult accessibility are anticipated. The characteristics of ceramic sheets in which scintillation materials are blended have been tested using a plasma source and a low-energy helium beam of 7 keV. Scintillation efficiencies are degraded by continuous bombardment of ion beams, and are saturated at doses exceeding 10^{17} ions/cm^2. The scintillation spectrum, the efficiency to electrons and the efficiency to ions are dependent on the materials blended.

1. Introduction

The self-heating of a DT plasma by fusion-produced alpha particles is the key to the realisation of self-sustainable ignition of a thermonuclear plasma for fusion reactors. Therefore, the study of the mechanism of alpha particle loss is an important issue. Measurement of the temporal behaviour of lost alpha signals, and measurement of pitch-angle and energy distribution on ITER will be useful to understand the underlying physics. Moreover, it is important to monitor the bombardment location and the heat load for machine protection.

Scintillator probes are detectors for measuring lost fast ions. The energy and pitch-angle of escaping fast ions, such as alpha particles, can be obtained using such a probe [1-4]. Scintillator probes are comprised of a scintillator plate fixed inside a metal box with an aperture on one of its sidewalls. When lost ions, which follow a spiral path through the aperture-slit in a magnetic field, strike the scintillator plate, the light signal produced is transferred to a CCD camera and a photo-multiplier array. The former takes two-dimensional emission images of the plate, and the energy distribution and pitch-angle distribution of lost ions can be obtained. The correlation of the energetic particles and MHD activities can be determined from the latter signal [3, 4]. Another candidate for alpha particle loss measurement also uses scintillators, each of which is fixed in a hollow on the first wall [5]. Scintillation light emission can then be measured by a filtered camera viewing the first wall through a plasma.

The detector performance is highly dependent on the scintillator performance. The required properties of a scintillation plate to be used on ITER are as follows: (1) high sensitivity to alpha particles, (2) low sensitivity to other ions, neurons, electrons, gamma rays, (3) stable emission at high temperature (573 K), and (4) mechanical endurance under conditions of high temperature and radiation exposure.

We have developed a new type of ceramic scintillator (patent pending) from inorganic ceramic compounds and various kinds of scintillation materials. Here, we present some properties of these scintillators evaluated experimentally with a plasma source and ion bombardment.

2. Experimental setup and results

Ceramic scintillators were manufactured from scintillation materials and inorganic materials hardened into the ceramic on a stainless steel plate of 25 mm × 25 mm. Four kinds of scintillation material, ZnS(Ag), ZnO(Zn), $Y_3Al_5O_{12}$(Ce), and $Y_3Al_5O_{12}$(Cr), have been tested upto now.

The first experiment was carried out using a linear plasma source measuring 7 cm in diameter. Typical plasma parameters were electron density of 1.0×10^{10} cm^{-3} and electron temperature of 5 eV. The ceramic scintillators were immersed in He plasma with a grounded potential. A typical electron current from the stainless steel plate with the ceramic scintillators was about 6 mA. The scintillation light was measured with a Photo-Multiple-Analyser (PMA-11, Hamamatsu Photonics, Hamamatsu, Japan) through an optical-fibre. Among the 3 kinds of scintillation material tested, ZnO(Zn) and $Y_3Al_5O_{12}$(Ce), showed typical scintillation spectra, indicating their sensitivity to electron bombardment.

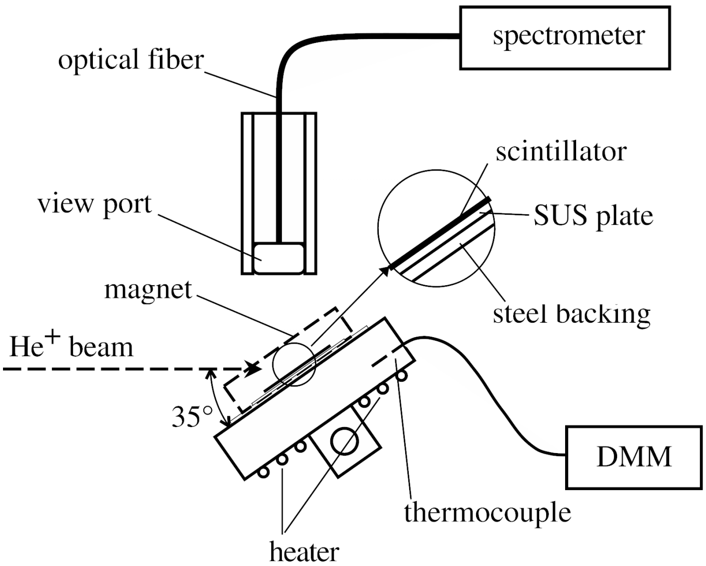

Fig. 1 Schematic view of the irradiation stage, with the scintillator holder, heater, thermocouple, a pair of permanent magnets to prevent electron bombardment, and a optical fiber coupled to a spectrometer.

The second experiment was carried out using a 7 keV He^+ beam, extracted from a bucket-type source of 8 cm in diameter and 9 cm in length, by a three-stage electrode system with holes 6 mm in diameter. The ceramic scintillators were bombarded by the beam about 60 cm downstream. The beam radius had expanded to about 40 mm in diameter at this position and the beam density was about 30 μA·cm^{-2}. Figure 1 shows a schematic view of the irradiation stage, where the scintillator holder can be heated with a sheath heater and the temperature is monitored with a thermocouple. The scintillator plate was tilted at an angle of

35 degrees from the beam axis, and the scintillation spectra were again measured with the PMA-11, through an optical-fibre from the direction of 55 degrees. To avoid contamination by electron bombardment, a pair of permanent magnets were fixed so that a vertical magnetic field was formed in front of the scintillator. Further check is needed to avoid the contamination. Figure 2 shows typical scintillation spectra from (a) ZnS(Ag), (b) ZnO(Zn), (c) $Y_3Al_5O_{12}$(Ce), and (d) $Y_3Al_5O_{12}$(Cr). Figure 2(a) and (b) show those from measurement without the magnets indicating that electron contamination has a non-negligible influence. Several sharp peaks (588 nm, 693 nm, *etc.*) were due to contamination of lines from the He plasma.

Figure 3 shows the changes in the scintillation efficiency of $Y_3Al_5O_{12}$(Ce) during the measurement, (a) with temperature, and (b) with dose. In case (1) in figure 3(a) and 3(b), the measurement was carried out when the heater was turned on to increase the temperature, and the heater was turned off at T = 517 K. In case (2) in figure 3(a) and 3(b), the measurement

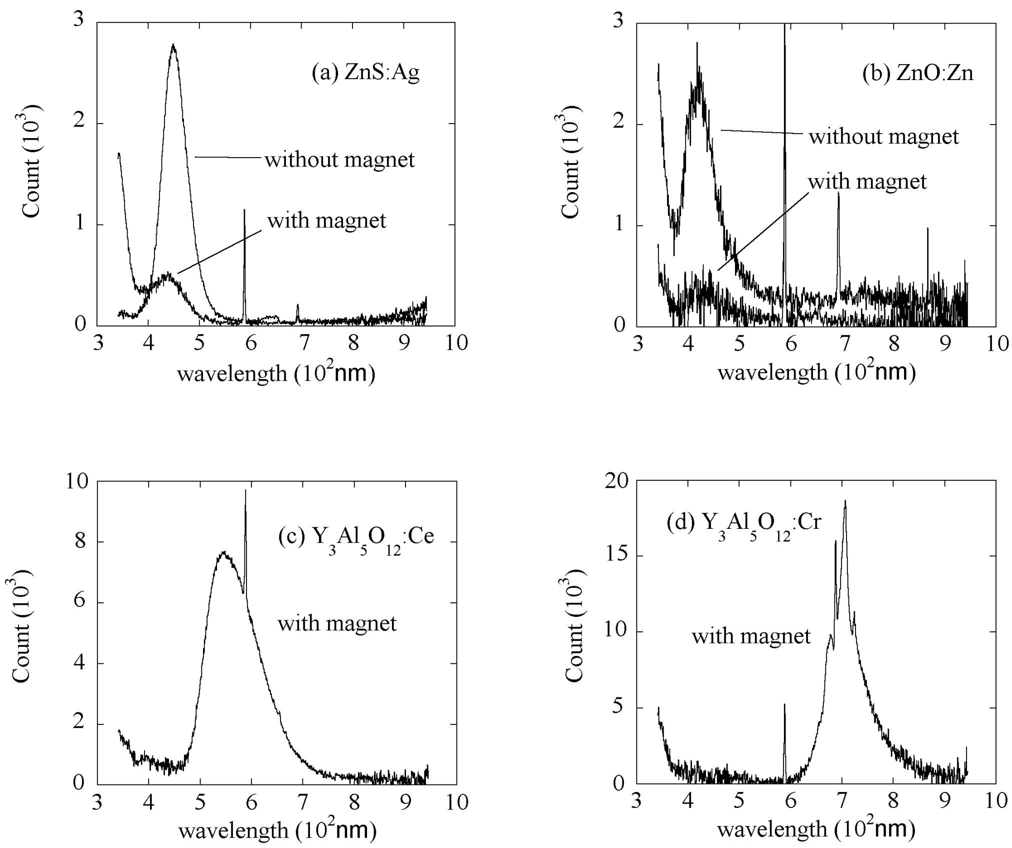

Fig. 2 Typical scintillation spectra from (a) ZnS(Ag), (b) ZnO(Zn), (c) $Y_3Al_5O_{12}$(Ce), and (d) $Y_3Al_5O_{12}$(Cr), with and without vertical field. (7 keV He^+ beam bombardment)

was carried out when the scintillator was preheated up to T = 501 K and then ion beam bombardment and measurement were started. These measurements indicate that the change in scintillation efficiency during measurement is not due to the temperature but is due to ion beam bombardment. The case (3) in figure 3(b) shows that the degradation was mitigated and the scintillation efficiency was saturated at doses exceeding 10^{17} ions/cm^2.

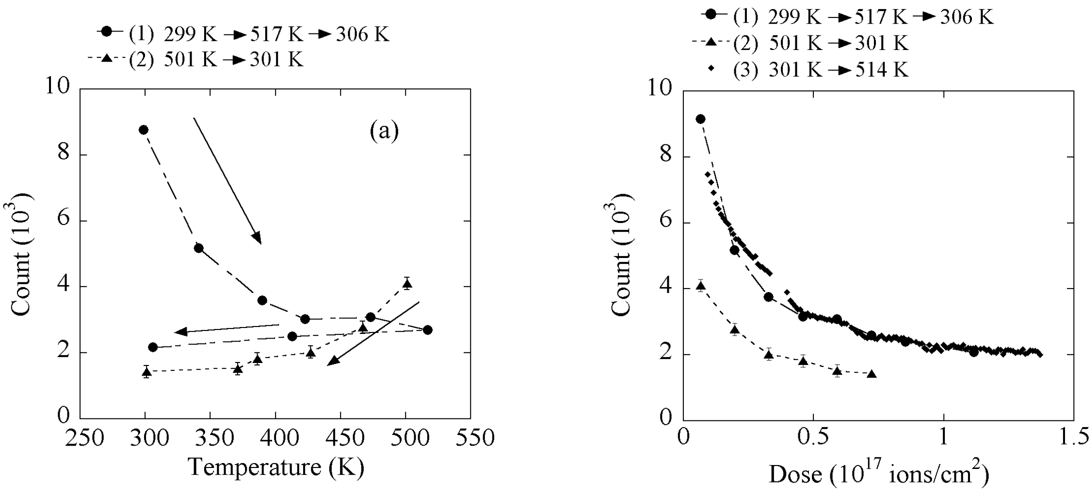

Fig. 3 Changes in scintillation efficiency of $Y_3Al_5O_{12}$(Ce), (a) with temperature, and (b) with dose.
(7 keV He^+ beam bombardment)

3. Discussion and Summary

Ceramic scintillators developed recently were tested at a temperature of $T = 514$ K. They had high scintillation efficiency and could potentially be used at ITER. The changes in scintillation efficiency due to continuous bombardment were saturated at doses exceeding 10^{17} ions/cm^2 for $Y_3Al_5O_{12}$(Ce). Further developments and experiments are planned, including the testing of new scintillation materials, and bombardment with 1–3 MeV alpha particles.

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