Characterization of scintillators for lost alpha diagnostics on burning plasma experiments

REVIEW OF SCIENTIFIC INSTRUMENTS **77**, 10E720 (2006)

Characterization of scintillators for lost alpha diagnostics on burning plasma experiments

M. Nishiura
National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

N. Kubo and T. Hirouchi
Department of Quantum Science and Energy Engineering, Tohoku University, Sendai 980-8579, Japan

T. Ido, T. Nagasaka, and T. Mutoh
National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

S. Matsuyama
Department of Quantum Science and Energy Engineering, Tohoku University, Sendai 980-8579, Japan

M. Isobe
National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

A. Okamoto, K. Shinto, S. Kitajima, and M. Sasao
Department of Quantum Science and Energy Engineering, Tohoku University, Sendai 980-8579, Japan

M. Nakatsuka and K. Fujioka
Institute of Laser Engineering, Osaka University, Osaka 565-0871, Japan

(Received 8 May 2006; presented on 9 May 2006; accepted 16 June 2006; published online 13 October 2006)

The characteristics of light output by ion beam irradiations under high ion fluxes have been measured for three kinds of scintillators: ZnS:Ag deposited on the glass plate, $Y_3Al_5O_{12}$:Ce powder stiffened with a binder, and $Y_3Al_5O_{12}$:Ce ceramics sintered at high temperature. The ion beam flux in the range from 10^{12} to 10^{13} ions/(cm^2 s) is irradiated to simulate the burning plasma experiments. The decrease of light output has been observed by long time ion irradiation. The deterioration of ZnS:Ag deposited scintillator is most serious. The deterioration has been improved for the scintillators of $Y_3Al_5O_{12}$:Ce with a binder and that sintered. Their applications to ITER lost alpha diagnostics are discussed.
[DOI: 10.1063/1.2228743]

I. INTRODUCTION

Lost alpha diagnostics on burning plasma experiments are strongly demanded, because the localization of alpha-particle loss may damage on the first wall and the plasma-facing components. However, it is difficult to use the conventional scintillator based lost alpha probe in hostile high temperature of more than 300 °C and the radiation environments with high flux ion bombardments. Although the basic characteristics of scintillators are reported,[1,2] the characteristics of scintillators are not clear in severe applications for burning plasma experiments. Therefore new types of scintillators have been developed using powders such as ZnS:Ag deposited on a substrate, $Y_3Al_5O_{12}$:Ce powder stiffened with an inorganic binder, and $Y_3Al_5O_{12}$:Ce ceramics sintered at high temperature. The characteristics of binder-containing scintillators have been studied using 3 MeV proton and helium beam fluxes of $\sim 10^{13}$ ions/(cm^2 s) relevant to lost alpha diagnostics in a burning plasma. The linearity of light emissions to the beam flux was confirmed. The temperature dependence of light emissions has the similar tendency as earlier results reported by Lin *et al.*[2] The degradation speeds of scintillation efficiencies are discussed for ITER lost ion probe.

II. EXPERIMENTAL SETUP

Scintillator characteristics for the light intensity and the irradiation endurance are investigated using the accelerator facility [Fast Neutron Laboratory (FNL)] of Tohoku University. In this facility, the beams of proton, deuteron, and helium ion of up to 4.5 MeV energy can be irradiated onto the scintillator samples. For the beam irradiation experiments, the vacuum chamber with the sample holder and the heater (the rated temperature of 600 °C) has been installed into the beam line, as is shown in Fig. 1. The sample holder has a rotary motion and is set to the angle of 45° between the sample holder plane and the beam axis. The sample temperature can be monitored by a thermocouple and be controlled by a proportional-integral-derivative (PID) controller. During the irradiation experiments, the vacuum pressure has been kept constant at 1×10^{-3} Pa, and the increase of sample temperatures by beam itself can be ignored. The emission light from a scintillator is measured by the spectrometer (Hamamatsu, PMA-11) from the side port of the vacuum chamber. This side port is also used as a beam profile monitor by a small charge-coupled device (CCD) camera simultaneously. The spectra, the sample temperatures, and the

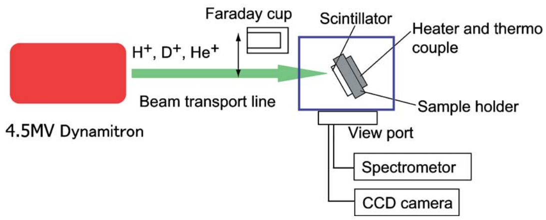

FIG. 1. (Color online) Schematic illustration of the beam line and the beam irradiation system.

beam profiles are stored into the hard disks of personal computers, which are controlled remotely from the control room of FNL.

The phosphor powders of ZnS:Ag and $Y_3Al_5O_{12}$:Ce are prepared for the irradiation of ion beams. The phosphor powder of ZnS:Ag (sample 1, P11, Sylvania) is deposited on the glass plate with a small amount of binder. This scintillator is employed for the lost ion probe of the Large Helical Device (LHD).[3,4] As for the powder of $Y_3Al_5O_{12}$:Ce, two kinds of samples are prepared to know their deterioration by the beam irradiations. For one sample, the powder of $Y_3Al_5O_{12}$:Ce (sample 2, P46, Sylvania) is mixed with the Aron ceramic binder (TOAGOSEI Co. Ltd) of 50 wt %, and is coated on the stainless steel plate. Since the Aron ceramic binder is mainly composed of Al_2O_3 and it has the heat resistance of up to approximately 1200–1300 °C, it is considered that the phosphor powder can be bonded on a substrate firmly, compared with the direct deposition on a plate without the binder. Another sample is the ceramic disk of $Y_3Al_5O_{12}$:Ce (sample 3, 1.0 mol % Ce is doped), whose powder is sintered at the temperature of ~1750 °C.[5]

III. RESULTS

A. Light output of scintillators

The measured spectra for samples 1, 2, and 3 have a broad peak at 450, 554, and 554 nm, respectively. The light output is measured by changing the beam current of 3 MeV proton at the room temperature for the linearity of the total emission light. In Fig. 2 for sample 3, both the peak and the integrated spectrum intensities are plotted as a function of the proton beam current. The spectra are integrated numerically over the measured wavelength. Before the beam irradiation, the beam current is measured by the movable Faraday cup placed at the 10 cm upstream. To control the fluence of ion beams, the beam irradiation is limited within a minute

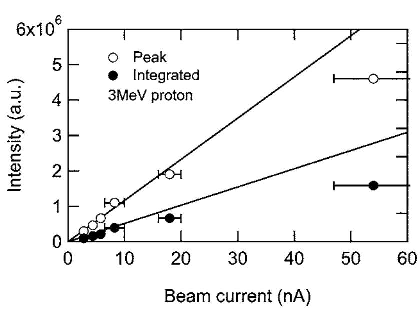

FIG. 2. Dependence of the peak and the integrated intensities on the beam current for the ceramic disk of $Y_3Al_5O_{12}$:Ce (sample 3).

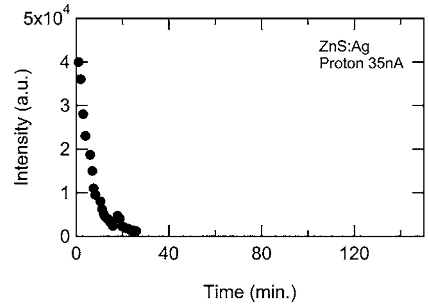

FIG. 3. Light output in the wavelength of 450 nm for ZnS:Ag (sample 1) by 3 MeV proton beam irradiation at the temperature of 17 °C. The proton beam current of 35 nA is irradiated, and the flux corresponds to 1.4×10^{12} ions/(cm^2 s).

for a spectrum acquisition. The peak intensity of sample 3 is linearly proportional to the beam current below 10 nA. At the beam current of 54 nA, the deviation of the measured data from the straight line is observed. It has a possibility that the deterioration of the scintillator surface has occurred due to the beam bombardments.

In the cases of other samples 1 and 2, there is the same tendency of the peak intensities in the range of the above experiment.

B. Deterioration by ion beams

In the burning plasma experiments such as that of ITER, the scintillator would suffer from the high particle flux in the range from 10^{12} to 10^{13} ions/(cm^2 s) and the high temperature operations around 300 °C behind the first wall. There are particular concerns about the deterioration and the optical quenching in those environments. To simulate the environments around the first wall of ITER, the beam flux is adjusted by both the beam current from the ion source and two dimensional slits perpendicular to the beam axis placed at a few tens of centimeters upstream. The beam sizes are determined from the CCD image data of the scintillator surface.

In the case of sample 1, the proton beam current of approximately 35 nA is irradiated for 25 min, as shown in Fig. 3. The proton flux becomes 1.4×10^{12} ions/(cm^2 s) with the measured beam cross section of 0.16 cm^2. Although the absolute intensity for sample 1 is the highest of the three samples, the peak intensity for sample 1 degrades to half of the initial one after 5 min. The deterioration by the beam irradiation is found to be the most serious for sample 1. The bonding strength is not tight enough to leave the phosphor powder on the glass plate with a small amount of binder.

For sample 2, the proton beam current of approximately 35 nA is irradiated for 140 min. The proton flux becomes 1.8×10^{12} ions/(cm^2 s) with the measured beam cross section of 0.126 cm^2. The result is shown in Fig. 4. We obtain the better properties of sample 2 than those of sample 1 in view of the deterioration. The heat treatment has been carried out in order to reveal the bonding performance of Aron ceramic binder. Figure 5 shows the effect of the heat treatment without baking and with baking at the temperature of 450 °C of sample 2 before the beam irradiations. The peak intensity is normalized by the initial one. Although the absolute peak intensity with baking becomes approximately three times

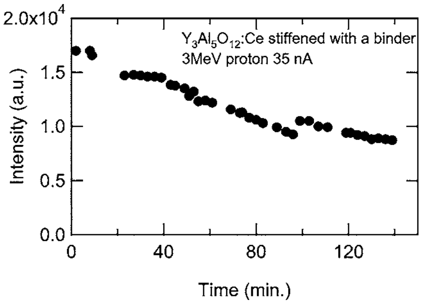

FIG. 4. Light output in the wavelength of 554 nm for $Y_3Al_5O_{12}$:Ce (sample 2) by 3 MeV proton beam irradiation at the temperature of 17 °C. The proton beam current of 35 nA is irradiated, and the flux corresponds to 1.8×10^{12} ions/(cm^2 s).

lower than that without baking in the initial irradiation, the deterioration by proton beams with baking is relatively weaker than that without baking. After a 120 min ion irradiation, the peak intensity with baking decreases by 60% of the initial intensity.

For the estimate of the damage for scintillators, the empirical equation is introduced as follows:

$$I_{\mathrm{int}} = a_1 + a_2 \exp(-a_3 t), \tag{1}$$

where the constants a_1, a_2, and a_3 are determined by the fitting as a function of the irradiation time t. In the case of

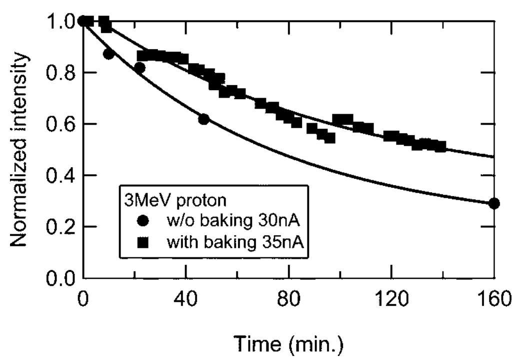

FIG. 5. The baking effect for $Y_3Al_5O_{12}$:Ce (sample 2) by 3 MeV proton beam irradiation.

sample 2 with baking, the constants a_1, a_2, and a_3 are estimated as 0.33, 0.72, and 0.01, respectively. For ITER experiments, substituting the total operating hours per year of 10^7 s into the above empirical equation (1), the peak intensity with baking would decrease to 0.33 of the initial one. The deterioration is within the permissible range. In addition to beam irradiations, however, the deteriorations and the background noise by neutrons and gamma rays would be considered in near future.

The characteristics of sample 3 were found to be similar to those of sample 2 and were evaluated with promising results in the beam irradiation at room temperature and 200 °C. As the phosphor powders prepared are not optimized for the doping density, the binder treatment, and so on, further investigation would be carried out to develop the better scintillators with the heat and radiation resistance.

C. Optical quenching by temperature

Each sample is heated up to 500 °C, and let it cool down back to the room temperature. The scintillators are irradiated by ion beams for a short time in order to avoid the deterioration. For samples 1 and 3, we obtain the same results as reported by Lin *et al.*[2] using their fitting functions. For samples 2, the improvement of light output has been observed in the temperature of more than 200 °C. Since the scintillator of ZnS:Ag quenches the light output at 300 °C, the developments of $Y_3Al_5O_{12}$:Ce or other phosphors are desired for ITER lost ion probe.

ACKNOWLEDGMENT

This work is supported by JSPS Grant Nos. 17340175 and 18035014 and NIFS05ULRR511.

[1] M. Tuszewski and S. J. Zweben, Rev. Sci. Instrum. **63**, 4542 (1992).
[2] Z. Lin, R. L. Boivin, and S. J. Zweben, Princeton Plasma Physics Laboratory Report No. PPPL-TM-392, 1992.
[3] M. Nishiura, M. Isobe, T. Saida, M. Sasao, and D. S. Darrow, Rev. Sci. Instrum. **75**, 3646 (2004).
[4] M. Nishiura *et al.*, Proceedings of Ninth IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, 9–11 November 2005, Takayama, Japan (unpublished).
[5] K. Fujioka (private communication).