Development of a Simple and Tough Alpha-Particle Detector Used at High Temperature

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Several ceramic detectors were made by use of the insulation layer formed on two types of substrate, i.e. aluminum and silicon. Each detector was irradiated with alpha-rays from an Am-241 source and the electric charge induced in the detector was measured in the temperature range from room temperature up to 450 K. The alpha-ray detection signals were well observed with an oscilloscope at the properly high bias-voltage only for very short time from several seconds to several tens of seconds before the start of the sweeping insulation breakdown. Though this type of the simple detector made of a thin ceramic layer can be hardly used for the energy analysis, it might be effectively applicable to the measurement of the flux of alpha-particles at high temperature.

Keywords: alpha-particle detector, ceramic detector, insulation breakdown, surface oxidation, anodic oxidation, alpha-particle flux monitor

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1. Inroduction

It is very important to measure neutrons and confined/escaping alpha-particles in the burning plasma experiments. It is well known that the self-heating of a DT plasma by alpha-particles is the key to realize a self-sustainable thermonuclear plasma. The alpha- diagnostics for a fusion reactor is reviewed in some recent papers [1,2]. As described in the review papers, it is still difficult to measure the distributions of confined and escaping alpha-particles and several proposals to solve such difficulties and related problems are now under examination [2].

We find difficulty in using normal alpha-particle detectors such as a semiconductor detector and a scintillation detector under the condition of high temperature. Ceramic material is fundamentally tough against the effects of high-energy particles, high temperature, high voltage and other severe conditions. Thus we have examined the possibility of the substitution of ceramic material for the semiconductor and scintillation material. If an alpha-particle detector is made of ceramic material, such a detector will be more effectively and conveniently used for the alpha-diagnostics. The purpose of this paper is to show fundamental data from some experiments for the development of the ceramic detector. At first, this paper describes how to make two types of ceramic detectors and then shows results on alpha-ray response of the detectors.

2. Experiment

2.1 Formation of detector samples

Several detector samples were formed on two types of substrate, i.e., aluminum and silicon. The thickness of the substrate was 0.5 mm. The surface of each substrate was first polished and then was oxidized for the formation of an insulation layer. Finally an about 400 Å thick silver film was made as an electrode on the insulation layer by an evaporation process. The size of the electrode was 10 mm in diameter.

The anodic oxidation method [3] was applied to the aluminum substrate (A-type detector) for the formation of the thick insulation layer on the surface, though the quality of the layer may be poor. A current of 500 mA was given to the aluminum substrate with an area of 5 cm^2 in a 3 % oxalic acid solution. The thickness of the formed aluminum oxide was adjusted to be less than 20 μm by the variation in the anodic-oxidation time.

The silicon substrate (B-type detector) was heated at 1300 K in air for the surface oxidation. A 100~200 nm thick insulation layer was considered to be formed in this way [4]. The formation of the thin insulation layer was checked with a low-voltage resistance meter. The thickness of the insulation layer of both A- and B- type detectors was adjusted to be smaller than the range of Am-241 alpha-rays in each insulation layer.

2.2 Measurement of alpha-ray response of detectors

Figure 1 shows a schematic drawing of the experimental arrangement and the measuring system for the examination of the alpha-ray response of sample detectors. The sample detector was set on a copper plate with a ceramic heater in a vacuum chamber. The temperature of the copper plate, monitored with a thermocouple, ranged from 283 to

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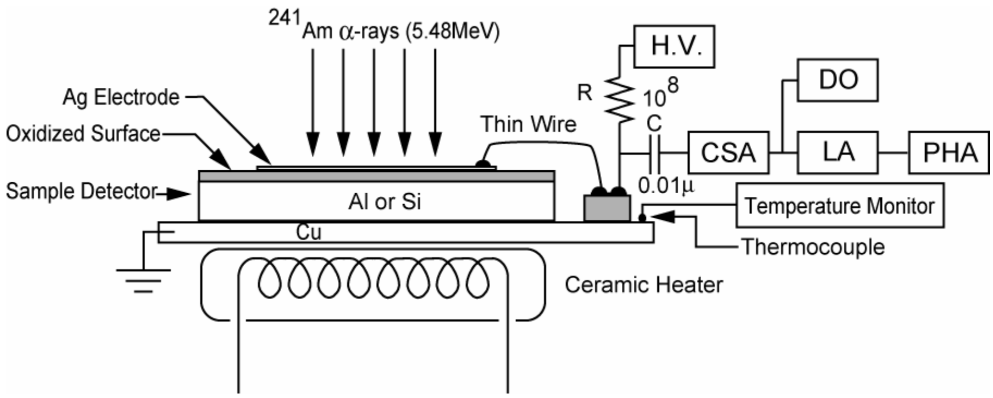

Fig. 1 Schematic drawing of experimental arrangement and measuring system for examination of α-ray response of sample detector.

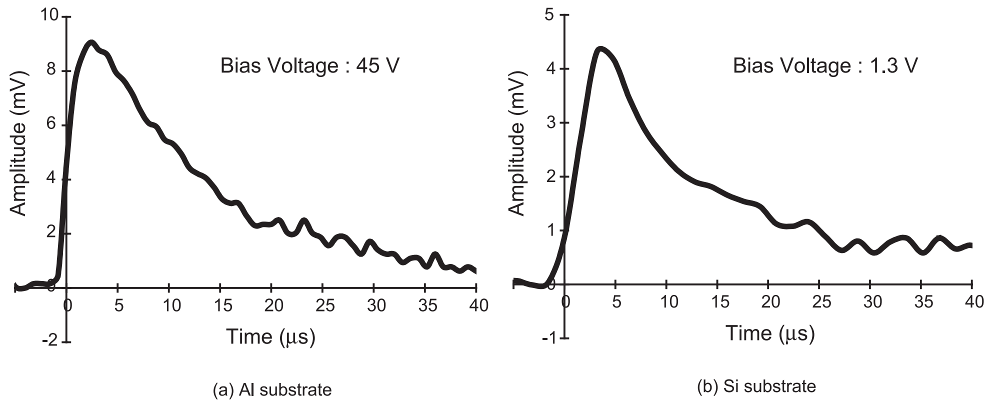

Fig. 2 Examples of observed output pulse shapes from CSA for α-ray detection with ceramic detectors ((a): Type-A , (b): Type-B).

about 450 K. The electrode on the insulation layer, in other words, the oxidized surface of the substrate was connected to a high voltage power supply through a thin wire. The bias voltage for the detector was adjusted to be 25 ~ 60 V for A-type detector and 0.5 ~ 3 V for B-type. Alpha-rays from an Am-241 source shot the thin oxidized insulation layer and the resultant electric charge due to the local insulation breakdown was measured with the electronic system which was composed of a charge sensitive amplifier (CSA), a digital oscilloscope (DO), a linear amplifier (LA) and a pulse height analyzer (PHA). The counting-rate of alpha-rays was about 10 cps during the measurement.

3. Results and Discussion

Figure 2 shows examples of observed output pulse shapes from the CSA for alpha-ray detections with the ceramic detectors. The alpha-ray detection signals were well measured at the properly high bias-voltage only for very short time from several seconds to several tens of seconds before the start of the sweeping insulation breakdown. Therefore, we could not satisfactorily store alpha-ray detection counts in PHA.

As shown in Fig. 2, the amplitude of output pulse shapes was below 10 mV, and this value corresponds to 1×10^{-14} C from the conversion gain of the CSA and is much smaller than the total charge stored in the capacitor of the detector itself. This result means that not the whole but partial discharge was caused by alpha-ray detection. The pulse amplitude from B-type detector was somewhat smaller than that from A-type detector. More detailed experiments and measurements are necessary for the discussion on the mechanism of the discharge in the ceramic insulator.

Once the sweeping insulation breakdown began, a large number of distorted pulse shapes were observed with the oscilloscope and this breakdown could be stopped by means of excessive decrease in the bias voltage. Figure 3 shows the relation between temperature and breakdown voltage for A-type and B-type detectors. The maximum, minimum and average values of the breakdown voltage are shown in the figure. The higher the temperature of the detector became, the lower the breakdown voltage. Moreover, the sweeping insulation breakdown at high temperature caused large damage in the insulation layer and degraded the insulation characteristics of the detector even at low temperature. These results were on the whole the same for both A and B type detectors.

4. Summary

Several ceramic detectors were made by use of the

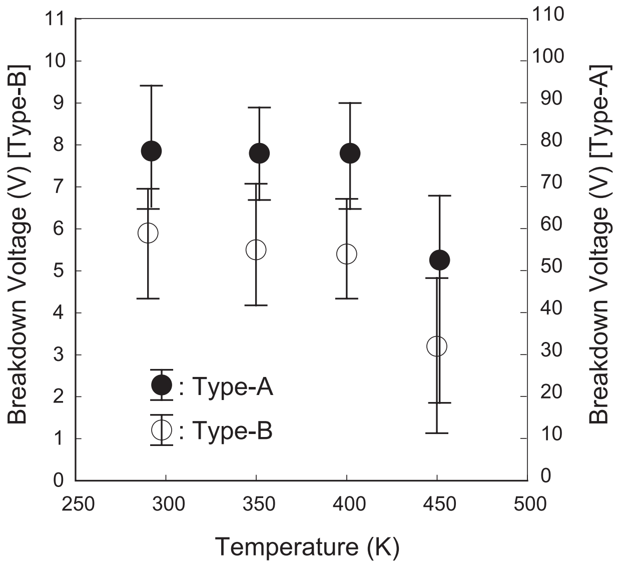

Fig. 3 Relation between temperature and breakdown voltage for ceramic detectors.

insulation layer formed on the two types of substrate, i.e., aluminum and silicon. The thin high-resistive ceramic layer of each detector was irradiated with alpha-rays from an Am-241 source and the electric charge induced in the detector was measured in the temperature range from room temperature up to 450 K. It was confirmed that the ceramic detector well detected alpha-rays at the properly high bias-voltage only for very short time from several seconds to several tens of seconds before the start of the sweeping insulation breakdown, though the amplitude of the output pulses varied widely. Though this type of the simple detector made of a thin ceramic layer can be hardly used for the energy analysis, it might be effectively applicable to the measurement of the flux of alpha-particles at high temperature. The practical use of ceramic detectors requires the establishment of the response stability and solutions for many problems such as the sweeping insulation breakdown, the degradation at high temperature and others. Further detailed experiments and discussion are necessary for the explanation of the mechanism of the discharge in the ceramic detector.

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