§15. Measurements of Radiation Induced Conductivity of Ceramic Insulators for Fusion Blanket

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Radiation effect data on electrical properties of ceramic insulators in the liquid Li/V blanket system are very important for a design of the fusion blanket system. In the blanket system, degrading of insulation performance becomes a serious problem in the condition of high temperature and high radiation dose rate. Thus, measurements of the radiation induced conductivity (RIC) on candidate ceramic materials (Y$_2$O$_3$, Er$_2$O$_3$, CaZrO$_3$, AlN etc.) have been performed with a fusion neutron generator and a fission reactor. In this report, moreover, detailed irradiation experiments on newly developed ceramic samples were performed with a $^{60}$Co gamma-ray source. Comparison of irradiation effects induced by different types of radiations and understanding of the difference in the irradiation effects are useful for the evaluation of the candidate materials.

The candidate materials with good chemical stability against high temperature liquid lithium were prepared for the irradiation experiments. Three disc specimens of Y$_2$O$_3$ (supplied from TEP Corp.), CaZrO$_3$, and Er$_2$O$_3$ (from TYK Corp.) were made with a sintering method, and their dimensions were 10 mm x 1 mm. For the electrical conductivity measurements of the specimens, appropriate electrodes were made with vapor deposition of silver. The thickness of the electrodes was ~30 nm. The electrical conductivity of the Y$_2$O$_3$, CaZrO$_3$ and Er$_2$O$_3$ specimens was order of $10^{-13}$-$10^{-14}$ S/m before irradiation.

The gamma ray irradiation was performed at the $^{60}$Co irradiation facility of Institute of Scientific and Industrial Research of Osaka University. The experimental setup was described in previous papers. The maximum dose rate at the sample position was estimated to be ~2.1 Gy/s by calculation with the photon-electron transport code. In addition, the same specimens were irradiated with 100 keV H$^+$ beams for the comparison between the gamma-ray and ion irradiation effects. The beam intensity was 0.6 – 2.2 μA/cm$^2$. The arrangement for the current measurement was similar to that in the gamma ray irradiation experiment.

Measured results of the current-voltage (I-V) curve under the gamma ray irradiation are shown in Figs 1 (a) and (b). The I-V curves of the three specimens were symmetric to the polarity of the bias voltage. The RIC values evaluated from the induced currents for bias voltage of +250 V were 1.3 x $10^{-6}$ S/m for Y$_2$O$_3$ (1.8 Gy/s), 1.7 x $10^{-11}$ S/m for CaZrO$_3$ (1.8 Gy/s) and 9.4 x $10^{-12}$ S/m for Er$_2$O$_3$ (2.1 Gy/s), respectively. In the ion beam experiments, the ion-induced conductivity was 2.9 x $10^{-11}$ S/m for Y$_2$O$_3$, 3.7 x $10^{-13}$ S/m for CaZrO$_3$, 3.9 x $10^{-11}$ S/m for Er$_2$O$_3$, respectively.

The RIC data evaluated from the present gamma ray irradiation experiment were compared with our previous data obtained by fusion neutron and fission reactor irradiation experiments. The dose rate for the fission reactor irradiation was reevaluated by detailed calculation of the neutron and gamma ray spectra with MCNP transport code. As shown in Fig. 2, the present data were plotted almost within one order of magnitude as compared with data from the previous irradiations. The results indicate that the RIC effect in the candidate materials is correlated with the dose rate under neutron and gamma ray irradiations, which deposit the energy uniformly in the materials. However, the magnitude of ion induced current was 1 or 2 orders lower than that predicted from the gamma ray and neutron irradiations as plotted in Fig. 2. The response under the ion beam irradiations was complicated and included various factors to be considered. Since the thin layer below the high-voltage-side electrode had high ion induced conductivity under irradiation, the specimen was considered to be a series of two regions with low and high conductivities. The density of electron-hole pair production under ion beam irradiation was estimated to be $10^7$ times higher compared with the gamma ray irradiation. Therefore, electrons and holes might recombine effectively and it is imagined that the electrical field near the high-voltage-side electrode was weakened due to the existence of the space charge (charge up).

![Fig. 1. Results of current-voltage (I-V) curve measurement under gamma ray irradiation.](image1)

![Fig.2. Comparison of radiation induced conductivity evaluated in present experiment with that in previous DT neutron and fission reactor irradiation.](image2)

References
3) T. Tanaka, et al., Fusion Engineering and Design, to be published.