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Electrical properties of mineral-insulated cable under fusion neutron irradiation

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Abstract

Degradation of electrical insulation property of mineral-insulated (MI) cables under fusion neutron irradiation was examined by use of Fusion Neutronics Source at Japan Atomic Energy Research Institute. Observed increase of leakage current in an MI cable (diameter; 4.8 mm, length; 2.0 m) was ~ 5.0 pA for the DT neutron flux of 2.9×10^7 n/cm^2/s and bias voltage of 200 V between the central wire and sheath. The bias voltage and neutron flux dependence of the leakage current indicates that the degradation of insulation property of the cable is dominated by the production rate and drift of electric charge in the insulator. Furthermore, the appearance of large transient leakage currents immediately after the start and stop of the irradiation and the growth of leakage current even for the bias voltage of 0 V imply that electrical properties of MI cables under irradiation are considerably affected by the distribution of electric charge trapped in the insulator.

Keywords: Mineral-insulated cable; Radiation induced conductivity; Fusion neutron irradiation; DT neutron

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1. Introduction

In fusion reactors, mineral-insulated (MI) cables are expected to be helpful for plasma diagnostic system, reactor control system and others because of their good properties of high electrical insulation, heat resistance and mechanical strength. However, in severe radiation environment of high dose rate, the insulation of an MI cable degrades because electric charge is induced in the insulator by radiations. So far, some experiments on electrical degradation of MI cables have been performed in material testing fission reactors [1–9]. More detailed and sufficient irradiation data on electrical properties of MI cables are required for the evaluation of the reliability of the system with MI cables for fusion reactors. In the present study,

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the degradation of electrical insulation of MI cables was examined under irradiation by use of a fusion neutron source.

2. Experiment

Effects of fusion neutron irradiation on MI cables were examined by use of Fusion Neutronics Source (FNS) at Japan Atomic Research Institute (JAERI). Fig. 1(a) shows a schematic drawing of the experimental arrangement and the block diagram of the measurement system. The MI cables had a coaxial structure consisting of a Cu central wire, sintered MgO insulator and a stainless steel sheath. Both ends of the cables were sealed with glass to protect them against humidity. Two types of MI cables were prepared for irradiations. Cross sections of the cables and their dimensions are shown in Fig. 1(b). The cables were 2.0 m in length and were bent into rings. The diameter of the ring was 26 cm (cable-a) and 14 cm (cable-b), respectively. The cables were placed in front of the tritium target bombarded by the 350 keV deuteron beam and were irradiated with DT fusion neutrons. The bias voltage was applied to the sheath of the cable and the central wire was connected to an electrometer. Leakage-current data were recorded continuously with a personal computer and a pen recorder. Changes in the leakage currents flowing into the central wire were measured at room temperature as an effect of radiation-induced conduction. The neutron flux was monitored with a ^{238}U fission detector. The maximum flux of DT neutrons was 5.6×10^7 and 3.6×10^8 n/cm^2/s for the cable-a and -b, respectively. Fifteen minutes irradiation and 15 min beam-off, i.e. stop of neutron generation, was repeated to observe the transient response. Contribution of 14 MeV DT neutrons to the total dose rate in the MgO insulator was estimated to be $\sim 88\%$ from transport calculation using the MCNP-4C code [10].

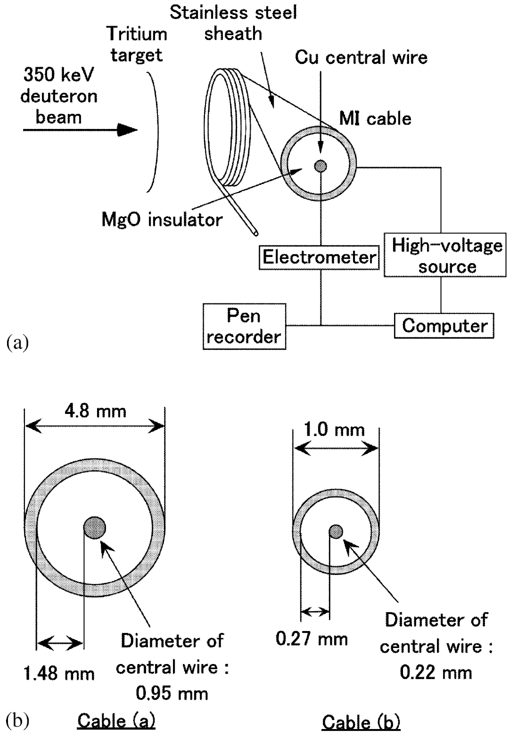

Fig. 1. (a) Schematic drawing of experimental arrangement and block diagram of measuring system. (b) Cross sections and dimensions of MI cables used in irradiations.

3. Results and discussion

Fig. 2(a) shows an example of increase in the leakage current induced by DT neutron irradiation for the cable-a. The neutron flux monitored during the measurement was also plotted in Fig. 2(b). A large peak of transient current was observed at the start of the irradiation, whereas the change in the neutron flux was almost stepwise. After several minutes, the leakage current settled down to a steady state. At the stop of the irradiation, the transient current flowed in the reverse direction. In the present paper, the steady currents measured during irradiations were examined as the induced currents.

The relation between the bias voltage and the induced current and that between the neutron flux and the induced current are shown in Figs. 3 and 4. Although the slope was gradual for intense electric field in the insulator as shown in Fig. 3, on the whole, the induced current was approximately proportional to the bias voltage and neutron flux. This indicates that the degradation of the insulation property was dominated by the production

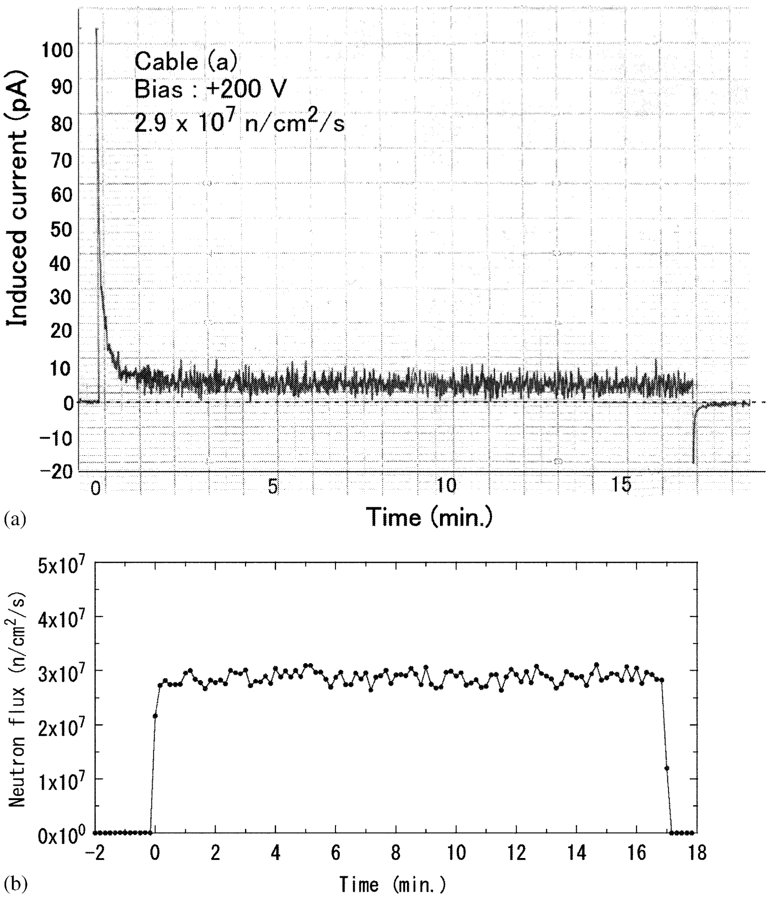

Fig. 2. (a) Example of increase in leakage current induced by DT neutron irradiation. (b) Change of neutron flux during current measurement shown in (a).

rate and drift of electric charge in the insulator. Even for the bias voltage of 0 V, a small leakage current was induced by irradiation. However, the direction of observed currents depended on the measurement history. More specifically, the direction of the induced current was negative after measurement applying positive bias voltage. Contrarily, positive current was observed after negative bias voltage was applied. Therefore, the plots around 0 V are scattered in Fig. 3.

Under the condition of the same bias voltage, the induced current in the thicker cable-a was about five times larger than the thinner cable-b as shown in Fig. 4. The amount of the electric charge produced by neutron irradiation in the insulator of the cable-a was estimated to be 27 times larger than the cable-b from the point of the volume. On the other hand, the strength of the electric field in the insulator of the cable-a was calculated to be about 1/5th of that of the cable-b from a simple analytical equation. The difference in the radiation susceptibility between the cables-a and -b can be explained from the product of the ratio of the production rate of the electric charge and the ratio of the strength of the electric field.

Similar transient peaks of the leakage currents at the start of irradiations were observed in our previous examination on sapphire plate specimens [11]. However, the reverse peak at the stop of the irradiation was observed for the first time in the present experiments. As to the sapphire specimens, the leakage current after the stop recovered slowly

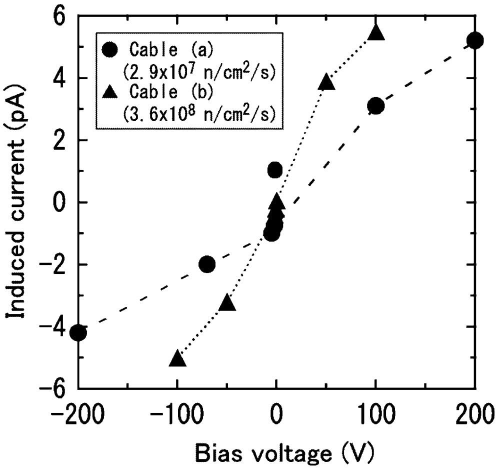

Fig. 3. Bias voltage dependence of currents induced by DT neutron irradiation.

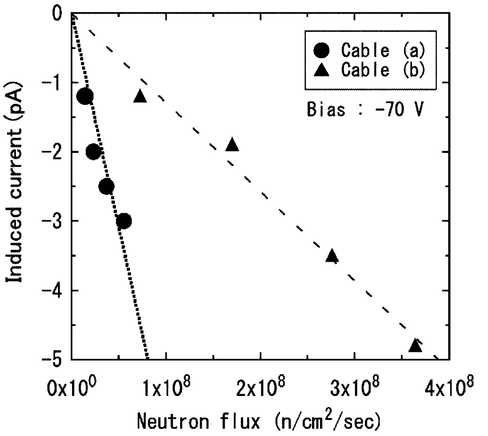

Fig. 4. Flux dependence of currents induced by DT neutron irradiation.

to the level before the irradiation [11,12]. In the insulator of the MI cables in the present experiments, the strength of the electric field around the central wire was estimated to be ~3 times larger than that near the sheath from an analytical equation. Therefore, the unbalanced distribution of the trapped electric charge may cause the pullback of the leakage current at the stop of the irradiation. The observation of the polarity of the leakage current for the bias voltage of 0 V may be also related to the unbalanced distribution of the trapped electric charge due to the gradient electric field of the coaxial structure. For the detailed and quantitative analysis of the experimental results, we need further data on the behavior of electric charge in the insulator.

4. Conclusion

Fusion neutron irradiation experiments on MI cables were performed for the examination of the degradation of their insulation property. Observed increase of the leakage current in the cable (diameter; 4.8 mm, length; 2.0 m) was ~5.0 pA for the DT neutron flux of 2.9×10^7 n/cm^2/s and bias voltage of 200 V between the central wire and sheath. The leakage current induced by neutron irradiation was approximately proportional to the neutron flux and bias voltage. This result indicates that the degradation of insulation property of the cable is dominated by the production rate and drift of electric charge in the insulator. The appearance of the large peaks of the transient leakage currents immediately after the start and stop of the irradiation indicates that the behavior of electric charge produced by neutrons is considerably affected by the distribution of electric charge trapped in the insulator. Moreover, the reverse current at the stop of the irradiation and the polarity of the leakage current for the bias voltage of 0 V may be related to the unbalanced distribution of the trapped electric charge due to the gradient electric field. Further data on the behaviors of electric charge in the insulator are required for the detailed and quantitative analysis of the experimental results.

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