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DYNAMIC IRRADIATION EFFECTS IN ELECTRICAL CONDUCTIVITY OF CERAMIC INSULATORS

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Ceramic electrical insulators will play important roles in heavy irradiation environments in nuclear fusion reactors, such as, for heating, controlling and diagnostic measurements of burning plasmas. Electrical conductivity of ceramic insulators is known to change dynamically and drastically under irradiation through phenomena such as so-called radiation induced conductivity (RIC). Also, electrical breakdown is apprehended to enhance under irradiation. Without actual fusion irradiation sources, high flux fission reactors are the most appropriate irradiation sources relevant to fusion irradiation environments. They have a relevant ratio of an electronic excitation rate to an atomic displacement rate. Also, their atomic displacement rate, namely up to about 10^{-6}dpa/s covers values expected in fusion reactors now under consideration. In-situ type experiments, namely measurements under irradiation, are essential to evaluate dynamic irradiation effects such as effects on electrical properties of ceramic insulators. Sophisticated experimental techniques were developed to measure electrical conductivity of ceramic insulators in high-flux fission reactors under well-controlled conditions, under the US/Japan collaboration named JUPITER (Japan USA Project on Irradiation Test using Reactors) project, using experimental fission reactors in Japan and the USA. The final experiment was carried out in a developed irradiation facility called the Temperature Regulated In-Situ Test Facility (TRIST) in the High Flux Isotope Reactor (HFIR) in Oak Ridge National Laboratory (ORNL). The experiment was named as JUPITER-TRIST-ER (electrical Resistivity measurements)[1,2,3].

Twelve different alumina (Al_2O_3) and sapphire (single crystal alumina) specimens, which are candidate insulators in fusion reactors, were irradiated and their electrical conductivity was measured in-situ during the reactor operation extending for about 3 months. The maximum dpa (displacement per atom) was about 2 dpa, which would cover the expected dpa in ceramic insulators in the ITER. The irradiation temperature was about 770K, where the RIED would take place most probably from reported experimental results.

Figure 1 shows change of measured electrical conductivity of sapphire. The electrical conductivity increased substantially, roughly from a value less than 10^{-9}S/m to about 10^{-6}-10^{-7}S/m as the reactor started to operate at its full power of 85MW and then it decreased to a value less than 10^{-9}S/m at a reactor shutdown. Changes were due to the phenomenon of RIC. Values of RIC of 12 different aluminas and sapphires were obtained as a function of electronic excitation dose rate and they satisfied design criterion of RIC being less than 10^{-6} S/m at an electronic excitation rate of 10^{-4}Gy/s.

The electrical conductivity under irradiation did not increase substantially in the course of 3 months irradiation in this. Some specimens showed moderate increase of electrical conductivity at the beginning of irradiation, however, the observed increase did not proceed to a catastrophic increase of electrical conductivity and to a resultant electrical breakdown. The results indicated that the RIED would not be a problem in a near and middle term fusion development.

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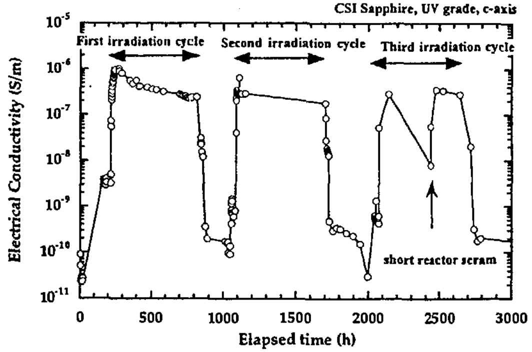
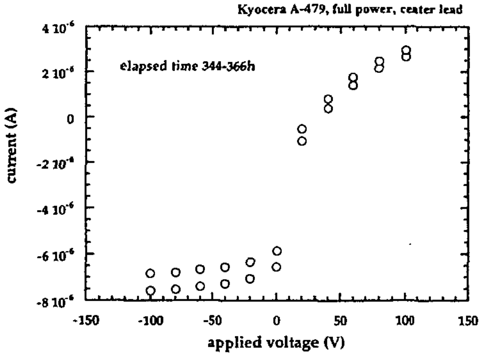


Figure 1 Electrical conductivity of highly pure sapphire in the course of HFIR irradiation

Figure 2 Non ohmic behavior of electrical conduction and offset current of alumina under HFIR irradiation



The experiment revealed some unique features of electrical conductivity of ceramic insulators under irradiation. A non-ohmic behavior was observed and a large offset current of up to a few tens micron ampere was measured as shown in Fig. 2. These peculiar behaviors of electrical insulators will impose serious engineering problems especially in instruments for plasma diagnostics. At the same time, these phenomena may reveal interesting physics in a system composed of ceramics and metals under irradiation. A supplementary experiment was proposed in a Japan Materials Testing Reactor (JMTR), to study these peculiar behaviors.

The paper will describe results of detailed analyses of non-ohmic behavior as a function of irradiation dose, as well as implication of the present results on fusion reactor developments. Also, origin of the observed large offset current will be examined, especially from a standpoint of its materials dependence.

References

[1] S.J.Zinkle, et al., submitted to J. Nucl. Mater..
[2] T.Shikama et al. presented at the 8th International Conference on Fusion Reactor Materials, October, Sendai, Japan, to be published in J. Nucl. Mater..
[3] T. Shikama and S.J.Zinkle, ibid.