SUMMARY OF ROUND ROBIN MEASUREMENTS OF RADIATION INDUCED CONDUCTIVITY IN WESGO AL995 ALUMINA — S. J. Zinkle (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to summarize recent measurements of the radiation induced conductivity of Wesgo AL995 polycrystalline alumina.

SUMMARY

This existing data on radiation induced conductivity (RIC) measurements performed on the same heat of the IEA reference ceramic insulator are summarized. Six different sets of RIC measurements have been performed on Wesgo AL995 at dose rates between 10 Gy/s and 1 MGy/s. In general, good agreement was obtained between the different groups of researchers. The data indicate that the RIC at a test temperature of 400-500°C is approximately linear with ionizing dose rate up to ~1000 Gy/s, and exhibits an approximately square root dependence on dose rate between 1 kGy/s and 1 MGy/s.

PROGRESS AND STATUS

Introduction

In order to obtain a better understanding of the radiation induced electrical degradation (RIED) process in ceramic insulators, an international round-robin RIED experiment was recently performed on the IEA reference ceramic insulator, Wesgo AL995 [1]. This well-known grade of polycrystalline alumina has been produced for over 30 years, and has good dielectric properties [2] and mechanical strength. As summarized elsewhere, significant levels of electrical degradation were not observed by any of the research groups involved in the round-robin RIED experiment [1]. In conjunction with this round-robin experiment, measurements of the radiation-induced conductivity were obtained over a wide range of ionizing dose rates. The purpose of the present report is to compile the RIC data obtained on this single heat of material. Recent RIC data obtained on the same heat of Wesgo AL995 in the HFIR TRIST-ER1 reactor irradiation experiment [3,4] are also included in this compilation.

Summary of Round-robin RIC Measurements on Wesgo AL995 Alumina

All of the specimens for the round robin tests on Wesgo AL995 alumina were machined from a single bar of material (IEA reference heat) that was obtained by Roger Stoller at ORNL [5]. A total of 6 different research groups participated in the round-robin experiment [4,6-10]. The irradiation sources for the in-situ radiation induced conductivity measurements included 1.8 MeV electrons [9], 28 MeV He ions [6], 104 MeV He ions [8], Lasref spallation neutrons [7], and the HFBR [10] and HFIR [4] fission reactors. All of the measurements except ref. [8] employed a guard ring electrode configuration to make the measurements. Most of the experiments [4,7,10] utilized a low-side electrical measurement technique in order to minimize leakage current artifacts (i.e., the high voltage was applied on the base electrode and the electrical signal from the guarded center electrode was measured on the low side of the electrical circuit). The electron [9] and 28 MeV ion irradiation [6] experiments utilized a high side measurement technique in order to avoid electrical current contributions from the irradiating beam. All of the RIC measurements were made at temperatures between 400 and 500°C, with the exception of the 10 Gy/s and 1.5 kGy/s dose rate measurements in the HFIR TRIST-ER1 experiment, which were performed at ~50°C and 170°C, respectively [4]. Further experimental details are contained in the original references [4,6-10].

The results of the six RIC studies on Wesgo AL995 alumina are summarized in Fig. 1 [4,6-10]. Two different specimens were measured for the HFIR irradiations. The HFIR data plotted at an ionizing dose rate of 10 Gy/s were obtained with the capsule inserted in the core prior to reactor startup [4]. This ionizing dose rate is based on rough calculations, and further analysis is underway to determine the accuracy of the quoted 10 Gy/s ionizing dose rate. The HFIR data plotted at 1500 Gy/s were obtained with the reactor operating at 10% power. Due to the nonohmic response of Wesgo AL995 observed in the HFIR TRIST-ER1 experiment [4], the electrical conductivities obtained from slope of the current vs. voltage curve for both positive and negative applied voltages are shown. The RIC data obtained from the negative quadrant are considered to be the most accurate representation of the bulk conductivity in HFIR [4]. Excluding the HFBR data, the results suggest that the RIC is roughly proportional to the ionizing dose rate between 10 Gy/s and ~1000 Gy/s, and that the RIC is nearly proportional to the square root of the dose rate between 1500 Gy/s and 1 MGy/s. The measured RIC value from the HFBR experiment [10] is approximately one order of magnitude lower than the HFIR data [4] at comparable dose rates. One possible contributing factor is that the HFBR conductivity data were obtained after a displacement damage level of 0.1 dpa had been reached. All of the other RIC data plotted in Fig. 1 were obtained for damage levels <0.01 dpa. Several studies have shown that the RIC in high-purity grades of alumina is decreased by irradiation damage, due to increased electron-hole trapping at the radiation-produced defects [11-15]. A decrease in the RIC value with increasing damage level was also observed for Wesgo AL995 in the HFIR experiment [4]. For example, the RIC measured at 15 kGy/s (450°C) decreased by about a factor of five in Wesgo AL995 after 1 dpa. An additional possible explanation for the low reported RIC value in the HFBR experiment is the possibility that some of the Pt electrode may have delaminated during the irradiation [10].

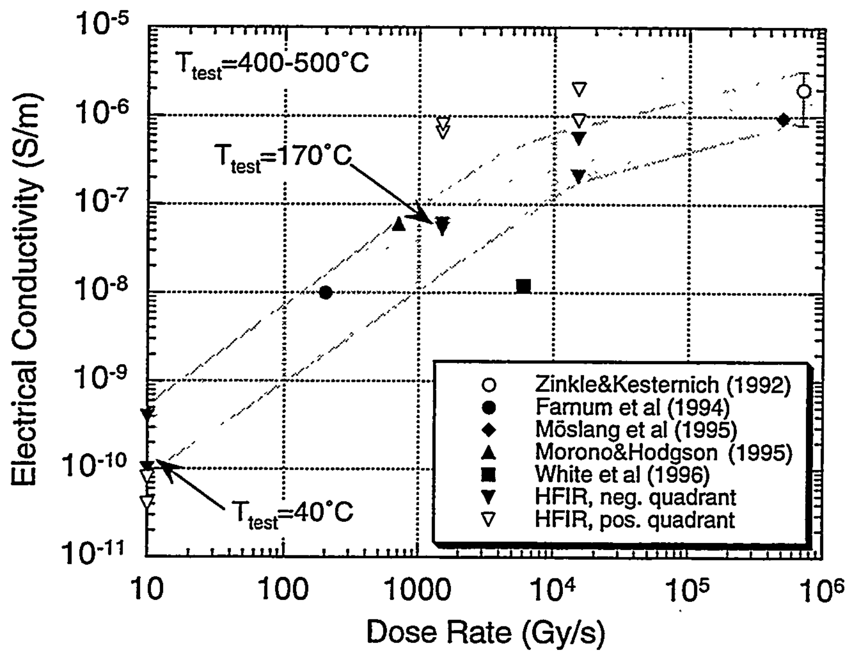

Figure 1. Summary of the round-robin RIC measurements on Wesgo AL995 alumina [4,6-10].

The temperature dependence of the RIC in Wesgo AL995 alumina is unknown. Previous RIC studies on other grades of alumina have shown that either a slight increase or decrease in RIC with increasing temperature is possible, depending on the details of the irradiation source and residual impurities in the insulator [11,16]. An initial RIC of ~$3x10^{-7}$ S/m was reported in ref. [17] for Wesgo AL995 irradiated in the HFBR reactor at 350°C, 6000 Gy/s. The Wesgo AL995 results summarized in Fig. 1 are somewhat higher than previously reported room temperature RIC values for Vitox (99.9% purity) polycrystalline alumina [18], and somewhat lower than reported room temperature RIC values for high-purity sapphire [16,19] and Wesgo AL998 (99.8% purity) and AL300 (97% purity) grades [19] of polycrystalline alumina.

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