§23. Dynamical Radiation Induced Effects in Electrical Property of Blanket Silicon Carbon Materials for Fusion Reactors

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Silicon carbides (SiCs) are potential candidates as insulating materials in nuclear fusion systems such as separators or insulating flow channel inserts, between tritium breeding and neutron multiplier materials composing Li-Pb blanket modules. For use as the insulator, it is significantly important to understand the radiation effects in the electronic conduction of SiCs. So far, it has been reported that the electrical properties of insulating ceramics are dynamically modified by electrons that are excited from valence bands to conduction bands by the so-called dynamic radiation effects [1, 2]. The present work within the EU-Japan Broader Approach (BA) materials activities is to understand fully fundamental aspects of dynamic radiation effects for SiCs; that is indicative of transportational behaviors of electrical carriers, which significantly contribute to electronic, ionic, and protonic conductions, for application of the SiC based ceramics and composites in advanced nuclear systems and future fusion devices.

In present study, silicon carbide (CVD-SiC) materials with high purity and density, synthesized by the chemical vapor deposition technique, have been focused for use as the insulator in the fusion blanket concepts, because of possessing low electrical conductivity below 10^{-5} S/m. In particular, in-situ volume electrical conductivity measurements for the CVD-SiC materials were carried out at temperatures ranging from 300 to 673 K under gamma-ray, clearly in order to understand the basic radiation response for the electronic conduction of the SiC matrix materials, which is not due to impurity but crystalline structure.

Figure 1 shows dependences of RIC (●), σ_{RIC}, (beam-on) and the base conductivity (○), σ_{BC}, (beam-off) on irradiation temperature as well as dose for CVD-SiC samples before, during, and after gamma-ray irradiation at a dose rate of approximately 3.6 Gy/s and several temperatures of 300, 373, 473, 573, and 673 K in vacuum. For the gamma-ray irradiation at room temperatures in the ranges of 296-308 K, elevated by gamma-ray-heating, the RIC, that is the initial rapid increase in the electrical conductivity, was similar to the results with the gamma-ray irradiation at 5.9 Gy/s. The σ_{RIC} value became approximately twice higher than σ_{BC}, which was lower than that at 5.9 Gy/s and commonly depended on the dose rate. After the σ_{RIC} value gradually increased up to a dose of approximately 10 kGy, it was very little change up to approximately 0.2 MGy. In addition, the σ_{BC} value was degraded up to twice one at 0.2 MGy, which was in good agreement with the result at 5.9 Gy/s. The RIC and RIED may be probably due to changes in electronic structure of Si-C bonding by ionizing effects. The migration of the excited free-electrons, migrating at the conduction band and sub-bands, occupied in the gap between the valence and conduction bands, allows the electronic conduction to be improved, where the sub-bands are produced due to impurities and defects such as vacancies and distortion of the structure [3, 4]. In addition, the excited electrons may be able to keep remaining at the conduction band and sub-bands for a long time even if beam-off, which is not similar to the radiation effects in the electrical property of the other insulators such as alumina and magnesia. For the temperature dependence of the σ_{BC} and σ_{RIC} values, the σ_{RIC} values at irradiation temperatures above 373 K were almost identical with the σ_{BC} values before and after irradiation. The activation energy for σ_{BC} was estimated to be approximately 0.41 eV. The value for σ_{RIC} is almost same with that for σ_{BC}, except for one at temperatures below approximately 323 K. Since the amount of the excited electrons, migrated by radiolysis at 3.6 Gy/s, is speculated to be extremely much lower than those thermally, the radiation-induced phenomena are not probably observed. In particular, if the irradiation temperature is higher and higher, the excited electrons rapidly drop to valence band and are not able to keep trapping at the conduction band and the sub-bands.

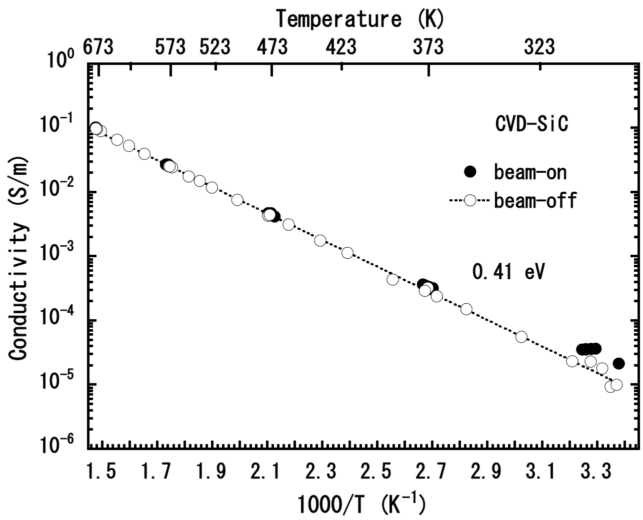

Fig. 1. Temperature dependence of (●) RIC, σ_{RIC}, and (○) base conductivity, σ_{BC}, of CVD-SiC, where σ_{RIC} and σ_{BC} represent data on 1.17 and 1.33-MeV gamma-ray beam-on at approximately 3.6 Gy/s, and 300 to 673 K in vacuum and -off, respectively.

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