Dielectric strength of two fiber reinforced plastics irradiated with heavy ions*

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Glass-fiber reinforced plastics (GFRP) are considered as structure support and electrical insulator for the new superconducting magnets at the Facility for Antiproton and Ion Research (FAIR). At FAIR, materials close to the beam tube will be exposed to high doses of secondary radiation of neutrons, protons, and heavier particles, possibly limiting reliable function and lifetime of device components. Typical GFRP used in accelerator magnets consist of woven glass-fiber fabrics embedded in a thermosetting polymer matrix. In superconducting magnets most commonly a G11-type composite [1] is used which consists of ~60% E-glass-fibers and an amine cured polyepoxy matrix.

Radiation hardness studies motivated by the International Thermonuclear Experimental Reactor (ITER) showed that neutron-irradiated composites consisting of a cyanate-ester matrix and S-glass fibers exhibit increased radiation resistance when compared with classical epoxy-systems [2]. In this study a classical G11-type epoxy/E-glass and an ITER-type cyanate-ester/S-glass composite were irradiated with heavy ions. For the irradiated samples, the dielectric strength (maximum electrical field strength at which the insulator fails) was determined.

G11-type epoxy/E-glass (thickness 1.0 mm) and ITER-type cyanate-ester/S-glass (thickness 1.4 mm) composites were provided by ISOVOLTA AG (ISOVAL® 11 HKB and cured ISOPREG CN). The G11-type epoxy is a commercially available product whereas the cyanate-ester composite is only available in the form of prepregs and was especially cured by the company for our tests.

The irradiation was performed at the Cave A of SIS18 with a 400 MeV/u Au-beam and slow extraction mode. The beam spot size was about 0.5 cm^2 and the flux of the order of 10^8 $cm^{-2}s^{-1}$. For each material three stacks consisting of three samples were irradiated. According to the SRIM-2010 code, the penetration depth of the Au ions is about 7 mm. The thickness of the sample-stack was 3 mm in case of G11-type and 4.2 mm in case of ITER-type material.

Breakdown voltage measurements were performed in silicon oil using an AC high voltage tester with round stainless steel electrodes 15 mm in diameter. The dielectric strength was normalized by the thickness and is presented in kV/mm.

Figure 1 shows the (AC)-dielectric strength of non-irradiated and irradiated glass-fiber reinforced plastics plotted as a function of irradiation fluence. The dielectric strength of the cyanate-ester/S-glass system is generally lower than the one of the commercial epoxy system. For irradiated classical G11-type composite, the dielectric strength decreases as a function of fluence and seems to evolve towards a limiting value of approximately 32 kV/mm at higher fluences. In contrast to this, the change in dielectric strength of irradiated cyanate-ester/S-glass composites is insignificant. Although, the ITER-composite is less affected by degradation, the irradiated classical G11 system has still a superior dielectric strength even at the highest fluence. It needs to be clarified whether the initial dielectric strength of the ITER-composite could be raised with an optimized curing procedure.

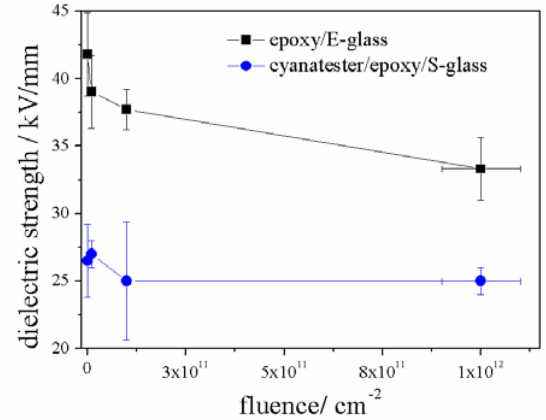

Figure 1: Dielectric strength of G11 and ITER-type plastic/glass-fiber composites versus fluence of 400-MeV/u Au ions. Lines are guides to the eye.

Earlier studies on ion-irradiated polyimide films showed a drastic decrease of insulating properties at rather low fluences [3]. The effect of ion irradiation for the analyzed composites is less pronounced probably because of the reinforcement with the inorganic glass-fibers prohibiting the formation of conductive ion tracks throughout the material.

For its usage at FAIR, both investigated composites show a tolerable decrease of dielectric strength within the tested range of ion fluences. However, a little caveat because the dielectric strength tests were performed ex-situ at room temperature and not considering low operation temperatures, thermal cycles or degradation due to dynamic mechanical forces.

[1] National Electrical Manufacturers Association, Standard LI-1, (1998).
[2] P.E. Fabian et al., Fusion Engineering and Design 61–62 (2002) 795.
[3] T. Seidl et al., Polymer Degradation and Stability 97 (2012) 2396.

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