RADIATION EFFECTS IN POLYCARBONATE CAPACITORS

by

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The aim of this paper is to examine the influence of neutron and gamma irradiation on the dissipation factor and capacitance of capacitors with polycarbonate dielectrics. The operation of capacitors subject to extreme conditions, such as the presence of ionizing radiation fields, is of special concern in military industry and space technology. Results obtained show that the exposure to a mixed neutron and gamma radiation field causes a decrease of capacitance, while the loss tangent remains unchanged.

Key words: polycarbonate, capacitance, neutron, gamma ray, radiation effect

INTRODUCTION

Dielectrics used as capacitor insulators have a wide range of physical and structural characteristics which give rise to differences in their electrical behaviour. Some of the most important characteristics of a dielectric capacitor are its polarization properties, electrical conductivity, power losses, and dielectric strength (maximum electric field strength it can withstand without breaking down). Exposure to radiation is among the factors which may influence these characteristics. The effects of ionizing radiation on dielectrics used as capacitor insulators may result in significant changes of capacitor performance within an electrical circuit.

The trend of using commercial off-the-shelf (COTS) circuits in satellite and spacecraft systems, and the inevitability of alternative dielectrics, such as polymers replacing the SiO_2, necessitate an evaluation of the performance of such materials in radiation environments. Their properties can be critical for the performance of the device in a high-radiation environment, regardless of the circuit architecture [1, 2].

RADIATION EFFECTS IN POLYMER DIELECTRICS

Figure 1 gives a schematic display of ionizing radiation effects in polymer materials. The influence can be divided into two phases. In the first phase, gamma photons give rise to secondary electrons by way of Compton scattering and photoelectric absorption. Neutron induced nuclear reactions give rise to alpha particles which go on to produce delta electrons along their tracks. Secondary electrons produced by the gamma and neutron radiation further interact with polymer macromolecules, causing their ionization and excitation [3, 4].

In the second phase, the relaxation of excited molecules and locally formed ionization clusters results in the formation of large amounts of free radicals. Highly reactive free radicals cause the destruction of polymer chains, either by chain scission (random rupturing of bonds) or cross-linking (formation of large, three-dimensional molecular networks). As a result of chain scission, low-molecular-weight fragments, gas evolution, and unsaturated bonds may appear [5].

Free radicals formed during irradiation can survive for several weeks before recombining. The ratio of resultant recombination, cross-linking, and chain scission depends on the chemical composition and

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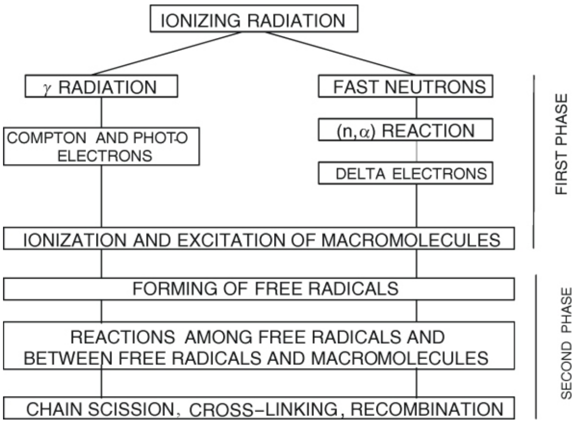

Figure 1. Ionizing radiation effects in polymer materials

morphology of the polymer, total radiation dose absorbed, and the rate at which the dose was deposited. Unlike polytetrafluoroethylene, polypropylene, or polymethyl-methacrylates, the physical properties of a polycarbonate remain virtually unchanged at low absorbed doses (<105 Gy). This occurs despite the relatively large chemical transformations and extremely long lifetimes of the formed free radicals [6, 7].

Stabilization techniques, aiming to increase radiation tolerance of polymers, make use of compounds acting as free radicals and electron scavengers. Free radical scavengers are capable of generating a large number of hydrogen radicals which terminate free radicals produced in the polymer by radiation. Electron scavengers degenerate into radical/ion pairs upon colliding with a high-energy electron. This mechanism reduces the energy of secondary electrons and can, thereby, reduce the damage caused by radiation in polymers. The combination of both electron and radical scavengers in polymers produces a complete protective effect. Although electron scavengers help stabilize the polymer macromolecule, they nevertheless cannot prevent the formation of radicals. These radicals must still be terminated with the help of free radical scavengers [6, 8].

Many important physical and chemical properties of polymers – such as molecular weight, chain length, entanglement, polydispersity, branching, and chain termination – can be modified with radiation. These structural changes alter the electrical properties of polymers used as dielectrics in capacitors, affecting the loss tangent and capacitance [6].

EXPERIMENTAL RESULTS AND DISCUSSION

Polycarbonate dielectric capacitors used in this research had a customary extended foil design with metallized electrodes.

Polycarbonate capacitors used in the examination of radiation tolerance had the nominal capacitance of 1 μF, nominal impedance of 10^{14} Ω, and nominal loss tangent of 15 10^{-4}. The capacitors were exposed to a mixed neutron and gamma ($n_{+}\gamma$) field from a ^{252}Cf source, encapsulated in the form of Cf_2O_3. The mass of the used ^{252}Cf radionuclide was 2.265 μg, its specific neutron and gamma emission rates 2.34 10^6 (μg s)$^{-1}$ and 5.3 10^9 (μg s)$^{-1}$, respectively. The average neutron energy of the ^{252}Cf source was 2.14 MeV, average gamma photon energy 0.88 MeV. All post-irradiation measurements of capacitance were performed at a fixed voltage frequency of 100 kHz.

Polycarbonate capacitors were exposed to three different levels of total neutron and gamma fluences (Φ_n and Φ , respectively), given in tab. 1, in ascending order. Each fluence level is marked by a number (n) shown in the first column.

Table 1. Values of neutron (Φ_n) and gamma (Φ_γ fluences used for polycarbonate capacitor *vs.* the fluence level number

n	Φ_n [10^{10} cm^{-2}]	Φ_γ [10^{13} cm^{-2}]
1	3.55	8.66
2	7.10	17.3
3	10.66	26

Values of capacitance measured immediately after irradiation are presented in fig. 2. The graph shows the decrease of the measured capacitance with fluence level number n , *i. e.* with the rise of fluence. The capacitance was measured again 120 hours after irradiation. The obtained values were all close to the nominal capacitance, leading to the conclusion that the effects of radiation had meanwhile been reversed.

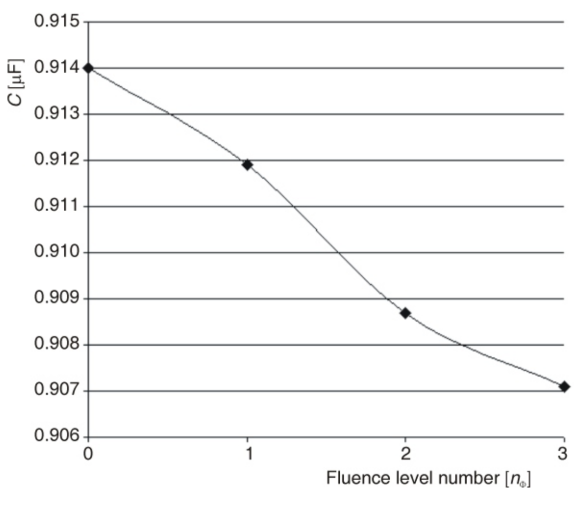

Figure 2. Capacitance *C* of the polycarbonate capacitor *versus* the fluence level number

As opposed to capacitance, no measurable influence of $n + \gamma$ radiation on the loss tangent has been detected.

The decrease of capacitance of polycarbonate capacitors when exposed to $n + \gamma$ radiation can be explained by the formation of ionic structures inside the dielectric volume. A higher concentration of ions in the dielectric causes a greater influence of ionic polarization on the dielectric constant of the material, leading to the decrease of capacitance. In addition, the local electric field of ionic structures performs a partial screening of the capacitor's electric field, albeit the change in the capacitance attributed to the screening is relatively small. A permanent presence of ionic structures inside the dielectric can cause its dielectric strength to decrease and thus accelerate the aging of the capacitor [6, 8].

The reversibility of the observed radiation effects is a result of the recombination processes inside the polycarbonate dielectric. The fact that the effects were reversed after a period of time shows that the absorbed doses were not high enough to produce permanent changes in the molecular structure of the dielectric.

CONCLUSIONS

The results of research on radiation hardiness of capacitors with solid polycarbonate dielectrics were presented in this paper. It was shown that the exposure to a mixed neutron and gamma radiation field causes a decrease of capacitance in polycarbonate capacitors. Radiation effects in the polycarbonate insulator were reversible at fluence levels used for this paper, but may lead to a permanent degradation at higher doses, accelerating the aging of capacitors. Further research should address the combined effects of high temperatures and radiation exposure, as well as stabilization techniques for the hardening of polycarbonate dielectrics to radiation.

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ЕФЕКТИ ЗРАЧЕЊА У ПОЛИКАРБОНАТНИМ КОНДЕНЗАТОРИМА

Циљ овог рада је да испита утицај неутронског и гама зрачења на фактор губитака и капацитивност кондензатора са поликарбонатним диелектрицима. Рад кондензатора изложених екстремним условима, као што је присуство јонизујућег зрачења, од посебног је значаја за војну индустрију и технологију свемирских летелица. Добијени резултати показују да излагање комбинованом пољу неутрона и гама зрака доводи до смањења капацитивности поликарбонатних кондензатора, док тангенс угла губитака остаје непромењен.

Кључне речи: поликарбонат, капацитивност, неутрон, гама зрачење, ефекат зрачења