COMPUTER SIMULATION OF RADIATION CHARGING PROCESSES IN SPACECRAFT MATERIALS

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Abstract

The problems of application of Monte-Carlo method to modeling of processes of internal charging of spacecrafts dielectric materials of under impact of electrons with energies 0.1 - 10 MeV, appropriate to range of energy spectrums of the Earth radiation belts electrons are considered. The dynamic model of internal charging including self-consistent calculation of internal electrical field and its influence to motion of primary and secondary charged particles is shown.

In terms of the simulation results, the differences between processes of internal charging of dielectrics in space conditions and in laboratory experiments in electron accelerators are explained.

Introduction

The radiation charging of spacecrafts is one of the most important factors resulting in to origin of failures in operation of the spacecraft onboard systems[1].

Last years, the increasing attention attracts the process of internal radiation charging of dielectric materials of spacecraft under impact of electrons with energies ~1–5 MeV, contained in the Earth's radiation belts. Earlier, it was considered on the basis of results of laboratory researches of accumulation internal charge in dielectrics at irradiation of ones by electron beams that this charging type is not implemented in space conditions[2]. However data of special experiments conducted onboard the CRRES spacecraft, crossing the Earth's radiation belts region, have shown convincingly that the origin of internal electric discharges in dielectric materials is possible in space conditions. For this purpose, the accumulation of electrons fluencies of ~10^{11} 1/cm^2 is necessary, and the value is less by order of 3 compared to the conditions of laboratory experiments[3].

The purpose of the paper is the computer simulation of the internal charging processes in spacecraft dielectric materials under impact of electrons with energies in an interval 0.1-10 MeV corresponding to range of the Earth's radiation belts electron energy spectra, and recognition on the basis of simulation distinctions in internal charging of dielectrics in space conditions and in laboratory experiments on electron accelerators.

Technique of Simulation of Dielectrics Internal Charging Dynamics

As the base of algorithms and programs package for simulation, the GEANT-3 software package developed initially for solution of fundamental problems in high-energy physics[4] was chosen. This package does not contain the utility to take into account the influence electrical field created by the absorbed internal charge on motion of the charged particles inside the dielectric. It is extremely important to take into account the influence in simulation procedures, because the electrical field mentioned substantially determines the depth distribution of the injected charge in dielectric. In this connection, the utility for simulation of influence of the internal electrical field on process of charged particles passing in substance was developed.

At the description of electron passing through the substance, the continuous energy losses on ionization in multiply scatterings with small energy transmissions in each collision and discrete processes with secondary electron and photon formation among which the dominating role is played by knockout of δ-electrons from energies above 10 keV were taken into account. At calculation of distribution of an accumulated charge in dielectric, it is necessary to take into account formation of an excess positive charge ("holes") after ionization of atoms also.

At simulation of process of dynamic accumulation of the internal charge in dielectric using the Monte-Carlo, approximation of "large" particles is used in fact. In the method, a set of N particles with a charge eZN and a given energy and incident angle distribution function of particles falling on the target in time Δt corresponds to each event. After modeling of one event and tracking of primary and secondary particles in the target, the increment of function of distribution of he internal charge $\Delta\rho(\mathbf{r})$ in given points is evaluated. In terms of the calculated distribution of the internal charge $\rho(\mathbf{r})$, electric field intensity E (**r**) and potential U (**r**) are calculated an the same points which will be used at simulation of following event. Thus, the series description of time development of the internal charging process, and also self-consistent calculation of the internal electrical field and its influence on motion of primary and secondary charged particles is carried out.

For estimation of probability of electrostatic breakdowns in dielectric and computation of the breakdown values, distributions of density of ponderomotive forces $\mathbf{F}(\mathbf{r}) = \rho(\mathbf{r})\,\mathbf{E}(\mathbf{r})$ and density of an internal energy of free charges $W(\mathbf{r}) = \rho(\mathbf{r})\,U(\mathbf{r})$ are evaluated too.

Calculation Results

On the basis of the technique developed, the computer simulation of the internal charge accumulation in the case of monochromatic beams of electrons and electrons with energy spectra typical for radiation belts of the Earth was done. Glass slab of width 0.5 cm was used as a sample. For modeling of laboratory conditions in accelerators, the energy of the collimated electron beam was 1.0-10.0 MeV. The energy spectrum of electrons of radiation belts of the Earth incident on the sample isotropically, was described by exponent with mean energy 0.5 MeV which is similar to models of conditions of “the worst case” for an internal charging developed in NASA[5] and DERA[6].

The depth distribution of the internal charge is one of the main characteristics determining the phenomenon of dielectric material charging under impact of the high energy electrons and possible discharge processes in dielectrics. As it was already noted above, this distribution is determined by as distribution of stopped electrons in the target (i.e. having energy below threshold), and by distribution of the produced positively ionized atoms (holes). Let's consider a case of the collimated electron beam with energy 2 MeV.

In Fig. 1a, the distribution of the stopped electron number (both primary, and secondary, basically, δ-electrons) is presented. In Fig. 1b, the similar distribution of number of positive vacant electron sites is adduced. As it is seen on Fig. 1ae, the distribution of stopped electrons is practically homogeneous till the depth of 0.25 cm, that is in good agreement with empirical formulas[7] and results of other calculations[8]. However, as it is seen from matching Fig. 1a and Fig. 1b that maxima determined by knock-out of δ-electrons exist in both distributions on small depth (~0.025 cm).

Net distribution of the internal charge (Fig. 2a) shows that the two distributions above substantially compensate each other, which is connected to small values of energies and correspondingly small range of δ-electrons. The considerable role in formation of these distributions is played by the electrical field of the internal charge.

Qualitatively different distribution of the internal charge is obtained at irradiation of the target by an isotropic electron beam with spectrum typical for the Earth radiation belt (Fig. 2b). Almost all internal charge has appeared to be concentrated in the surface area with depth less than 0.01 cm. It is determined by three reasons: presence of low energy particles in the spectrum, significant fraction of particles with small incident angle in the case of isotropic distribution and retarding field of the internal charge. Thus, density of the absorbed internal charge for space radiation considerably exceeds density of charges for the case of the monoenergetic collimated electron beam at small depth.

Computations of the electric field strength in laboratory (Fig. 3a) and space (Fig. 3b) conditions yield depth distribution close to each other as in curve shape, as in absolute value. Significant difference in the electric field intensity magnitude arise at small depth (lower 0.01 cm) where the magnitude value in space increases the value in laboratory conditions by a factor of 2.

Conclusion

Thus, characteristics of the arising internal charge considerably differ in case of laboratory simulation experiments in accelerators and in space conditions of spacecraft charging of in the Earth radiation belts. The indicated differences allow to explain the origin of internal electric discharges in dielectrics in space conditions at considerably lower values electron fluencies as contrasted to the laboratory experiment condition.

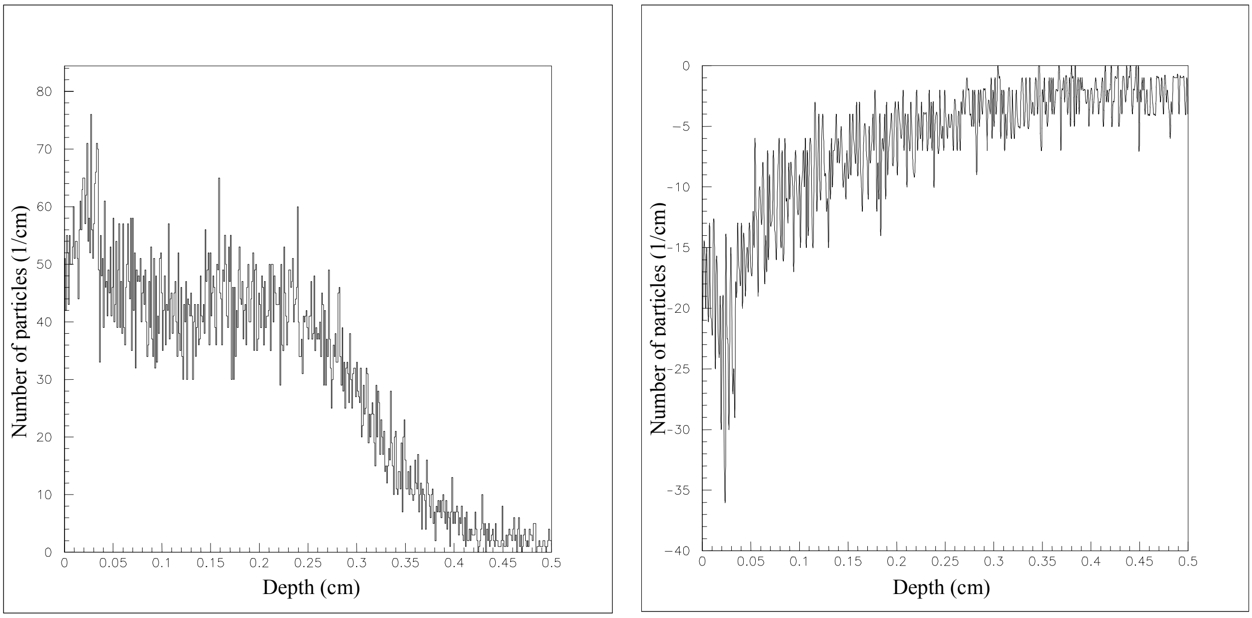

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Figure 1. Distribution on depth of a sample of number of charged particles for a monochromatic beam with energy 2.0 MeV at normal incident angle.

A. Distribution of stopped electrons; b - distribution of positively ionized atoms.

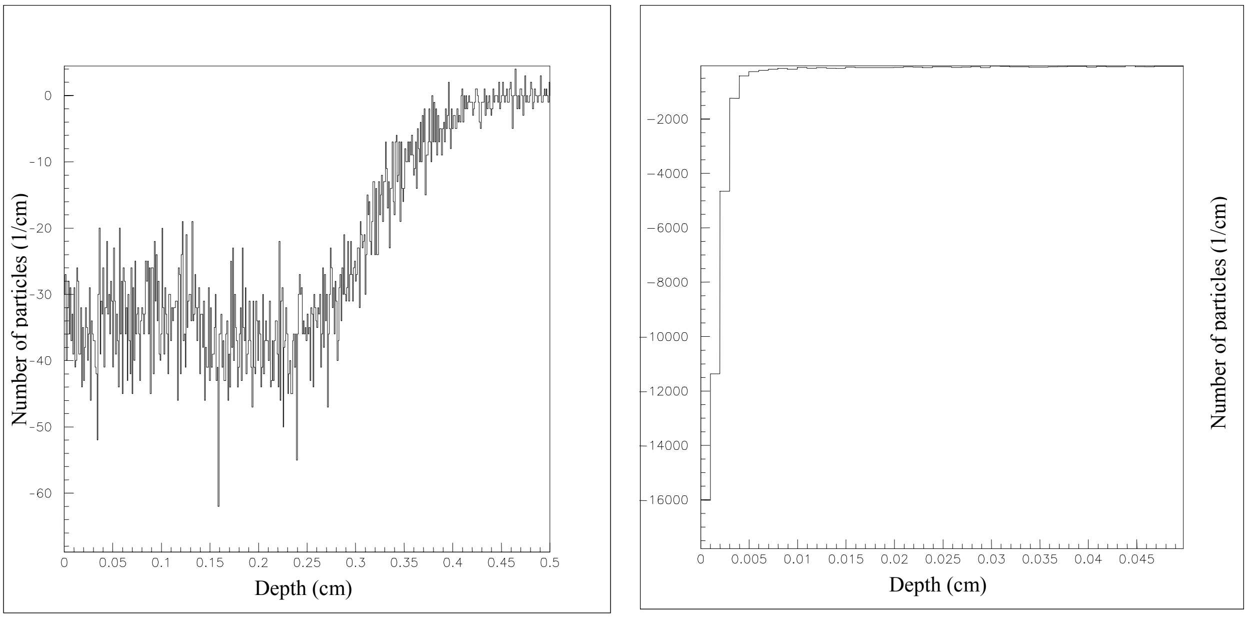

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Figure 2. Internal charge distribution on depth of sample.

A. For a monochromatic beam of electrons with energy 2.0 MeV at normal incident angle;

B. For Earth radiation belt electrons spectrum with isotropic angular distribution.

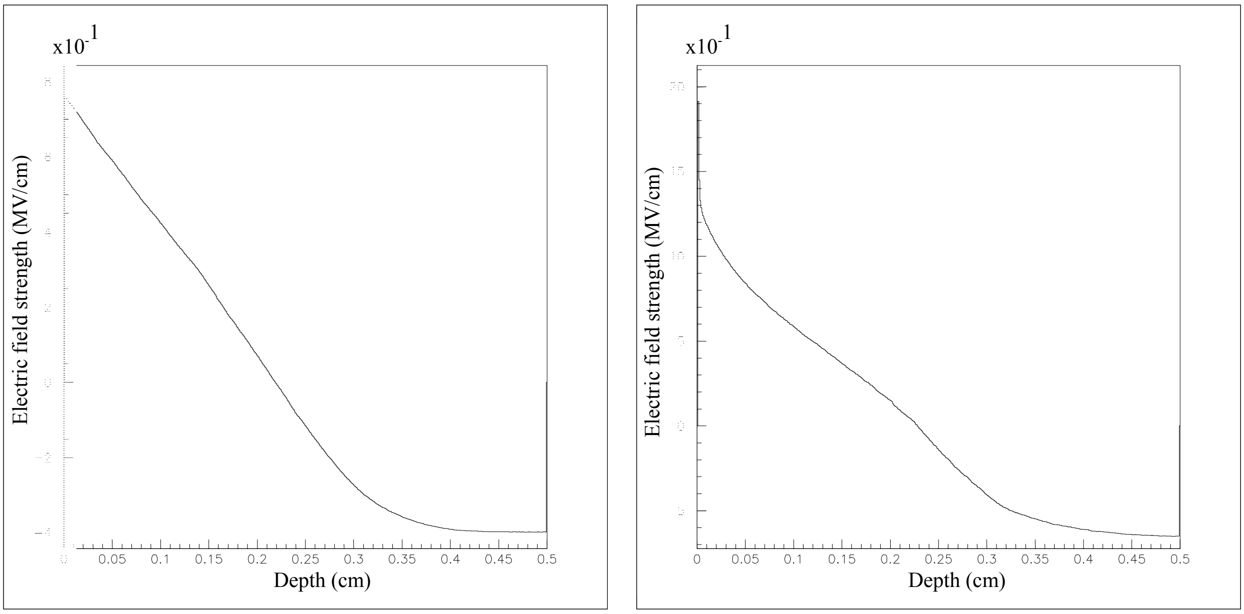

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Figure 3. Electric field strength distribution on depth of a sample.

A. For a monochromatic beam of electrons with energy 2.0 MeV at normal incident angle;

B. For Earth radiation belt electrons spectrum with isotropic angular distribution.

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