Monte-Carlo simulation of high energy electrons accumulated inside a PTFE film

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Various dielectrics are used as thermal control materials to maintain spacecraft electronics in the desired temperature range. PTFE(poly tetra fluoro ethylene,Teflon®) or Polyimid(Kapton®) are typical materials for good heat-resistant and high insulation characteristics. When they are used as surface heat control material, they are exposed to severe space environment such as plasma and radiation environment, and dielectric charging occurs. An electric discharge is caused when the electric field induced by the accumulated charges reaches the insulation strength, and then dielectric breakdown occurs. This leads to spacecraft failure and malfunction. For reliability improvement and longevity of spacecraft, it is necessary for spacecraft to analyze the charging phenomena inside dielectrics. Also, it is indispensability to develop analyzing technology to suppress and prevent spacecraft charging.

Spacecraft charging can be categorized into surface charging and internal charging. Most previous studies focused on surface charging in a low-energy plasma environment and theorized that differential surface charging may result in catastrophic discharges. Recently, however, it has been pointed out that besides surface charging there is possibility that internal charging is also related to discharging of spacecraft. Although there are some practical estimations of discharge criteria based on empirical equations, numerical simulations based on first principle are important to understand the phenomena. Clarifying the charge accumulation process inside insulating polymers will assist in the analysis of spacecraft failures and allow the prediction and prevention of dielectric breakdowns that might occur under severe electron irradiation in space.

In the present research, the charge accumulation processes inside a PTFE film are investigated by numerical simulations based on the Monte Carlo methodology to address collision processes. Each injected electron is tracked three-dimensionally based on the quantum consideration of the elastic and inelastic scattering processes between electrons and atoms consisting of PTFE (C2F4) described by Palov et al. Electron-phonon interaction and trapping effect are also included in the estimation of total cross section. Simulation results of an incident electron beam with energy of 20 and 30 keV are presented. In order to verify the computations, electron irradiation experiments are conducted based on a measurement technique previously developed by our research group. The computed results are compared with that of obtained in real-time measurements of the charge distributions inside PTFE film. Because the particle tracking method with Monte-Carlo methodology is probabilistic technique, vast number of particles should be used to obtain accurate result and the computational load becomes heavy. Therefore we introduced a parallel computer with 8 Pentium4 processors to conduct the computation.

Simulated results show that charge accumulation process inside a PTFE film can be accurately reproduced by the present simulation technique. Qualitative agreement can be seen with other simulation result and experimental result about charge density distribution especially the position of charge peak. It is an important analysis tool in engineering, but these can help radiation study under space environment if we establish technique to estimate the energy and fluence of incident particles from observed electric charge distribution.