Internal Charging Simulation of 3-D Structure with Narrow Gap

Zhenlong Zhang, Tao Yang, Hansheng Zheng, Jianwei Han, and Lihua Zhu

***Abstract*—Computer simulation is the main method to evaluate the threat of internal charging. Usually, the virtual object in programs is flawless, and some structural details, e.g. little crack, are ignored. Such idealized simulation may significantly underestimate the actual risk. In this paper, the charging potentials and electric fields of two 3-D structures without/with a narrow gap were calculated and compared. The results indicated that the charging status is remarkably influenced by the gap.**

Keywords—internal charging; 3-D simulation; spacecraft; gap

I. INTRODUCTION

Internal charging that induced by energetic electrons is one of the main space environment effects. The enhancements of outer belt electrons are often associated with many satellite anomalies, especially which travels in geosynchronous orbits or middle earth orbits [1]. For spacecraft internal charging effect, computer simulation is the main method to evaluate the charging threat and validate the protection design of a satellite mission. Initially, several one-dimensional assessment codes, such as NUMIT [2] and DICTAT [3], have been developed for determining the development of electric field and potential in irradiated insulators. In recent years, with the remarkable advance of computer technology, it is becoming possible to analyze charging conditions within realistic structures, and developing three-dimensional simulation tools has become a trend [4-6]. Whether 1-D or 3-D simulation, while the calculated electric field exceeds a breakdown threshold, e.g. 10^7V/m, then the computer program assumes that breakdown will occur. However, many calculation results for engineering application show that electric field exceeding the breakdown threshold is a rare event, even in the worst-case electron flux conditions, but in reality there are evidences that discharging might occur. One of the reasons is that the objects established in the program are in an ideal situation (for example, uniform material, smooth surface and well grounding), and some structural defects that existing in reality are ignored. These defects include manufacturing defects and aging defects. Such as there are two materials, originally should contact well each other, but for some reason, a narrow gap appeared between them. Then the presence of this narrow gap will significantly affect the development of electric field and potential during charging in space, and finally, it will dramatically alter the risk of breakdown.

In this paper, the charging potentials and electric fields of two typical structures were calculated by a three-dimensional internal charging simulation tool. For each structure, there are two different setting, without gap and with a narrow gap, and the results of this two setting were compared.

II. SIMULATION TOOL

A. Introduction of SIC3D

SIC3D is a three-dimensional tool for spacecraft internal charging, that was developed by the Space Environment Effects Laboratory (SEElab) of the National Space Science Center (NSSC) [4]. SIC3D uses Geant4 to electron transport calculation, and a finite-volume partial differential equation solver to solve the coupled Poisson's equation and continuity equation in three-dimension

$$\nabla \cdot (\varepsilon \nabla \varphi) = -\rho \tag{1}$$

$$-\frac{\partial \rho}{\partial t} = G - \nabla \cdot (\mu \rho \vec{\mathrm{E}}) + \nabla \cdot (\sigma \vec{\mathrm{E}}) \tag{2}$$

Where ε is the permittivity, σ is the conductivity, μ is the mobility of charge, ρ is the density of charge, φ is the potential, $\vec{E} = -\nabla\varphi$ is the electric field vector, and G is the electron deposition rate.

For a 100keV to 10MeV electron, while it interacts with a material, the physics processes involved are Ionization, Bremsstrahlung and Multiple scattering, these processes are described respectively by G4eIonisation, G4eBremsstrahlung and G4eMultipleScattering classes in Geant4. The secondary particles, such as electrons, positrons and photons also are taken into account.

After several years of development, this 3D simulator has a friendly interface and relatively easy to use now. Figure 1 is the interface of SIC3D.

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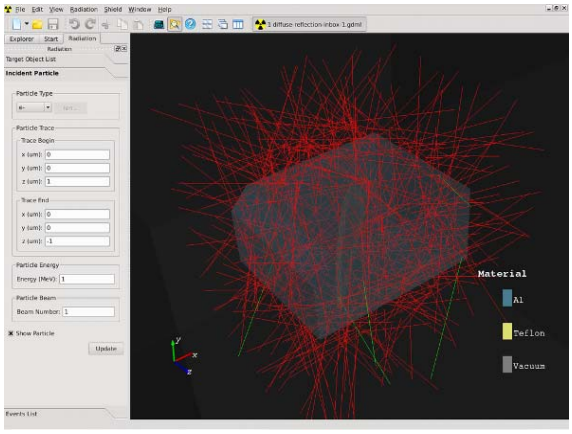
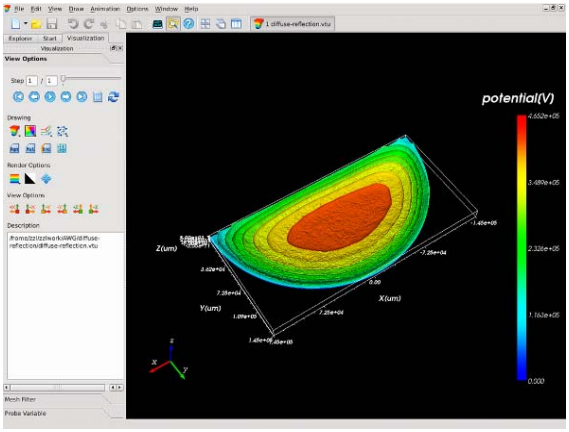


(a) Electron transport calculation.



(b) Electric field and potential calculation.

Figure 1. The interface of SIC3D

B. *Validation of SIC3D*

While SIC3D was developed, there were no other three-dimensional internal charging simulator could be use to compare with, so DICTAT was engaged to validate the outputs of SIC3D, i.e. the charging conductions of a slab was calculated by SIC3D, then the results were compared with DICTAT.

The maximal electrical fields of several polyimide slabs with different thickness were calculated by DICTAT and SIC3D respectively, and the results are shown in Table 1. In these calculations, uniformly, the ground condition was “inner surface” and the irradiation condition was normally incident 0.5 MeV electron beam. From Table 1, the results of SIC3D and DICTAT were similar while the slab is thicker, but the SIC3D results were significantly smaller than DICTAT while the slab is thinner, especially while the slab thickness is nearly to the electron range. Analysis proved that the reason of this difference is mainly attributed to the simplistic depth-dose models of DICTAT (see Figure 2). So we corrected the electron transport method of DICTAT by Tabata formulas, and then developed a new 1-D internal charging simulation tool [7]. The results of this “corrected DICTAT” were also listed in Table 1, and its results were more consistent with that of the SIC3D.

Table 1. Comparison of the charging results with different PI thickness

thickness （mm）	E_{max} （V/m）		
	DCITAT	DICTAT_C	SIC3D
0.5	1.4E+05	4.3 E+04	6.1E+04
1.0	8.1E+05	2.3E+05	3.6E+05
1.2	7.4E+06	5.2E+05	7.5E+05
1.5	7.4E+06	4.7E+06	5.3E+06
2.0	7.4E+06	7.4E+06	7.2E+06
3.0	7.4E+06	7.4E+06	7.2E+06

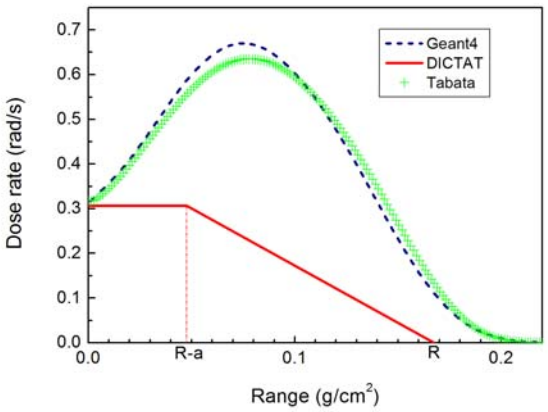
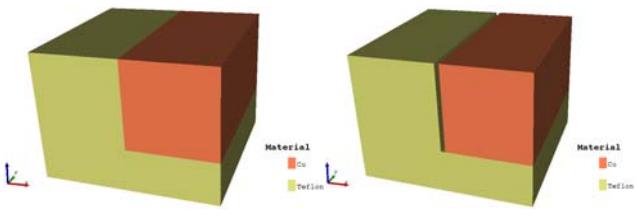


Figure 2. Dose rate as a function of depth in polyimide for a normally incident 0.5 MeV electron beam

III. SIMULATION RESULTS

A. *Simulation Results of Structure A (Part of Slip Ring)*

Figure 3 shows the geometries and materials of one simulation object. The size of this cube structure is 4mm×4mm ×3mm. In figure 3 (a), the dielectric part and the conductor part are connect tightly, but in figure 3 (b), there is a 0.1mm narrow gap between the two materials. The dielectric material is Teflon and the conductor material is Cu (grounded). The electron environment in calculation was worst-case short-term GEO spectrum [1] and the directionality is isotropic. Between the structure and electron environment, there is a 1mm aluminum shielding.

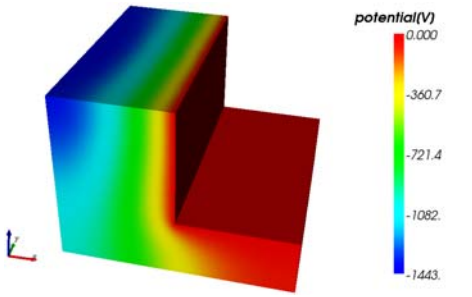


(a) Without gap. (b) With a marrow gap.

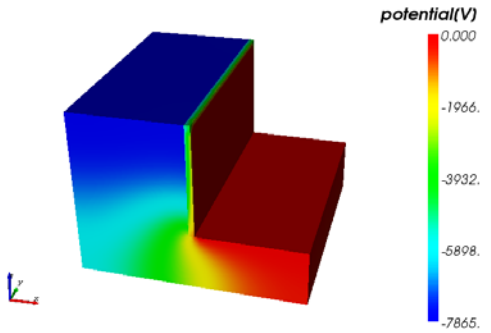
Figure 3. Structure A that modeled in SIC3D

The calculation results of potentials and electric fields are show in figure 4 and figure 5 respectively. The results show

that the potential increased form -1443V to -7865V and the electric field increased form 2.3×10^{6} V/m to 1.2×10^{8} V/m while the narrow gap appeared.

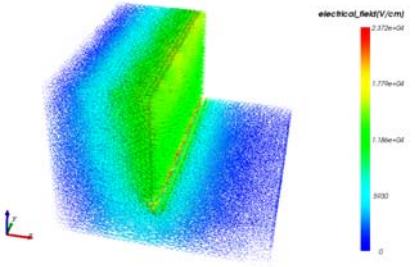


(a) Without gap

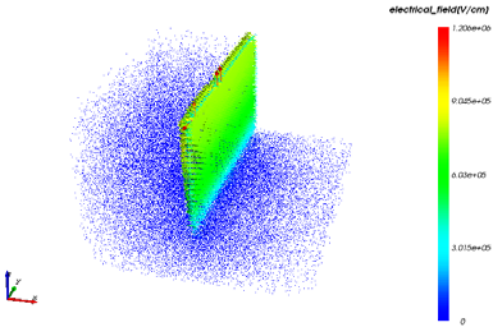


(b) With a marrow gap

Figure 4. Distribution of potential in structure A

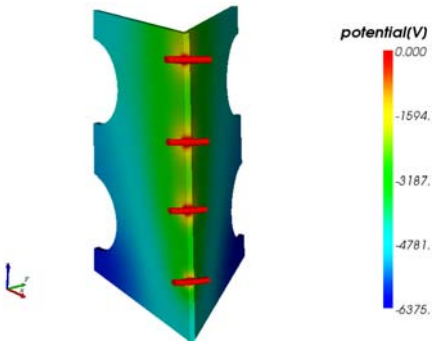


(a) Without gap

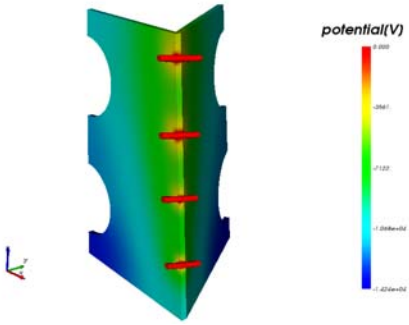


(b) With a marrow gap

Figure 5. Distribution of electric field in structure A

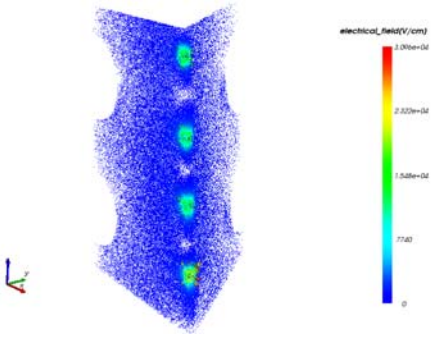


(a) Without gap

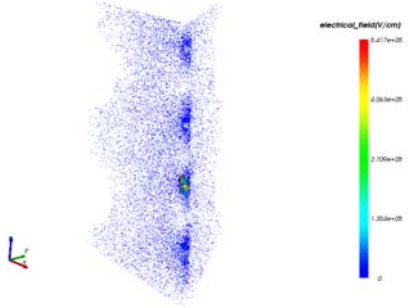


(b) With a marrow gap

Figure 6. Distribution of potential in structure B



(a) Without gap



(b) With a marrow gap

Figure 7. Distribution of electric field in structure B

B. *Simulation Results of Structure B (Part of Antenna)*

Figure 6 and 7 show the results of another structure. This structure is part of an antenna. The height of the structure is 92mm. In figure 6 (a), the spiral coil (four red columns) is connect tightly with the dielectric edge at all four contact points, but in figure 6 (b), there is a 0.1mm narrow gap at the third contact point. For this structure, the dielectric material is cyanate ester and the spiral coil material is Cu (grounded). The electron environment in calculation was worst-case short-term GEO spectrum [1] and the directionality is isotropic. The calculation results show that the potential increased form -6375V to -14240V and the electric field increased form 3.1×10^{6} V/m to 5.4×10^{7} V/m while the narrow gap appeared.

IV. CONCLUSIONS

This study preliminarily indicated that the charging electric field and potential status are remarkably influenced by the detailed features of the structure. The above two calculating example provided some quantitative description of this influence, that is a narrow gap can increase the maximal electric field more than ten times, and then exceed the breakdown threshold. Certainly, there are some common characteristics in this two calculating example. Firstly, the narrow gap appeared between dielectric and metal, thus cut off part of charge leakage path. Secondly, the narrow gap created a high potential difference between its two sides. These also should be avoided in the design.

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