Improved Simulation Method of Multipactor in Microwave Components for Space Application

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Multipaction discharge resulting from the continual increase of secondary electrons due to the secondary electron emission (SEE) phenomenon is a fundamental and influential phenomenon in many significant applications such as satellite transceiver system, ultra high-power antenna, dusty plasma, accelerators, and high power microwave (HPM) systems, causing power dissipation, electrical performance degradation, surface damage and even irreversible device destruction.

In recent years, much effort has been devoted to the research on multipaction investigation. Based on the parallel-plate approximation and Monte Carlo kinematical motion model, the susceptibility curve established by the European Space Agency was taken as a classic standard for multipactor design. But the discharge threshold obtained from the curve is only reliable for plates. It was modified by R. Udiljaket al. and applied in the theoretical analysis of multipaction in coaxial lines, elliptical waveguide and other 2-D structures. Since 1990s, based on the development of the full-wave electromagnetic simulation method and Particle-in-cell (PIC) technology, some actual systems, including iris waveguide filter and HPM windows, were simulated in 3-D space and the breakdown threshold analyzed under ideal condition. However, depending on the finishing condition and some surface treatments for SEE suppression, secondary electron yield (SEY) of the same material may vary to a large extent. Especially for microwave components with fabricated surface structures, multipaction simulation and threshold prediction remains a key challenge.

Challenges lie in several aspects. Firstly, it is impossible to model the micro-structures of smaller than micrometer scale on the surface when the microwave components are of centimetre and even larger scale. Secondly, the SEY properties of the porous surfaces depend dramatically on the processing condition, which is very difficult to quantify.

In this paper, effects of the secondary electron emission phenomenon on arbitrary surface states of metal in the multipactor analysis are investigated numerically and experimentally. Especially, effects of different surface treatments and the resulting surface states, including artificially fabricated micro-structures and random porous distributions, on the resonant electronic multipaction in actual microwave components have been investigated.

Due to the great discrepancy between the dimension scales of the microwave component and the micro-structures on the surface, it is not possible to establish models both of the component and the micro-structures simultaneously in the three-dimensional multipaction simulation. And it is demonstrated that it is the secondary electron emission properties of the micro-structures that affect the multi-generation electron collision and multipacting mostly.

Based on the physic dimensions of the surface micro-structures, including the height, width and distribution density, Monte Carlo kinematical motion model of electrons in the micro-structures has been established and the corresponding electron trajectories obtained. Then, the multi-generation electron emission from the micro-pores are calculated and the equivalent SEY obtained. Finally, the equivalent secondary electron emission model has been established and used for the quantization of the variation of the surface states.

For the validation and correction of the equivalent SEE model, witness samples with plat, randomly porous and artificially constructed porous surface have been fabricated with the component simultaneously and measured for the extraction of the secondary electron yield data. The secondary emission yield (SEY) and the energy spectrum measurements are performed on the chemically cleaned and in situ vacuum baked samples under different surface treatments. The SEE data are used for the fitting of the equivalent secondary electron emission model. Then, we establish the uniformed SEE model for the same material with arbitrary surface states, which is applicable for the smooth, the randomly rough and the treated surfaces.

Furthermore, an enhanced simulation method of multipaction in microwave components with different surface treatments has been proposed. In on our previous work, the self-consistent algorithm which is capable of modelling the interaction between electrons and fields has been established based on the finite-difference time-domain(FDTD) method and PIC method. The equivalent SEE model has been established and fitted by the measured data. The equivalent SEE model characterizes the surface collision and emission behaviours accurately and links the big discrepancy between these two dimension scales of the components and the surface micro-structures. Together with the electromagnetic Particle-In-Cell technologies, the nonlinear dynamics of multipacting electrons in the macroscopic microwave cavity and the relatively microscopic surface structures is intuitively investigated for the first time.

In conclusion, we establish the multipactor simulation method for arbitrary surface micro-topography. Moreover, an impedance transformer was utilized for validation of the simulated multipactor threshold, which matches well with the experiments. It is demonstrated that the random roughness affect little the multipactor discharge breakdown. It is the height-to-width ratio and the distribution density of the surface pores that determine the effects of the surface treatment on secondary emission properties and the resulting multipactor threshold. When the height-to-width ratio is big enough and the distribution of these pores dense enough, the SEE phenomenon can be suppressed effectively and so does the multipactor effect in practical components.