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Enhanced Dynamics of Multipaction Suppression in Dielectric Microwave Components with an External Magnetic Field

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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 space thrusters, dusty plasma, high gradient accelerators, laser-plasma accelerators, high power lasers, and high power microwave (HPM) systems. In recent years, with the wide spread of high-power microwave components in space applications, multipaction issues have attracted increasing attention and have become an area of intense research [1-3].

For the high-power DC and pulsed system, mechanisms of the single-surface dielectric multipaction breakdown have been profoundly researched [4-7].For the suppression of multipaction, an external static magnetic field B has been applied. The hopping frequency $\Omega = eB/m$ of electrons is much large than the frequency of the field Erf. Then, the secondary electrons get less energy from the field due to the dramatic reduction of flying time. Then the multipaction effect can be suppressed effectively as the collision energy is depressed to lower than the first cross over energy of the secondary electron yield of the material. However, the multipaction still occurs when the input power increase to an ultra-high level. Particularly, Chang et al. proposed a novel method for multipaction suppression by using a low-amplitude static magnetic field, the orientation of which is perpendicular to both of the electron velocity and the radio field [8,9]. And the intensity of the magnetic field B is properly set to make the hopping frequency Ω of electrons is closing to the angular frequency of the field ω. The collision energy of electrons increases dramatically due to the increasing of the flying time. The multipaction effect can be suppressed when the collision energy is larger than the second cross over energy of the secondary electron yield of the material. These analysis and the resulting dynamic models are applicable for the single-surface multipaction in the pulsed high-power system.

However, due to the limitation of the double surface structure and the input power of the microwave components, the low-amplitude magnetic field for multipaction suppression is not applicable any more. In this paper, based on the Monte-Carlo method, the dynamic model of multipacting electrons in the dielectric microwave components have been established, where the direction of the field changes in each half cycle and the resonant electronic multipaction occurs not only on a single dielectric disk but also between two plates. Especially, effects of external magnetic field have been investigated and applied in the ferromagnetic components.

The intensity of the radio-frequency (rf) magnetic field is two orders of magnitude lower than that of the electric field and can be neglected. Assuming the TE-mode rf electric field $Erf = -E\sin(\omega t+\theta)$ x,the accumulated positive space charging field Edc x, and the external magnetic field B, the motion equations of the electrons can be established and so do the trajectory equations. The transverse transition time of electrons between the dielectric plates can be obtained with the boundary condition.

The external magnetic fields parallel to and perpendicular to the electric field Erf have been investigated respectively. When the magnetic field is parallel to the electric field Erf, the electron cyclotron force ev×B is small as the majority of the secondary electrons are emitted with a small angle to the normal direction of the surface. For the field intensity that is lower than V/m at 1~10GHz, the external magnitude field that is smaller than 3T can be neglected.

When the magnetic field is perpendicular to the electric field Erf, the motion mode of the secondary electrons emitted with several eV of energy changes and the resonant steady state of electron multipaction causing by the phase focusing effect can be perturbed. Depending on the magnitude of B, the dynamic model of the electron motions varies. When the magnitude of B is close to or even lower than the rf magnitude field, the bending effect can be neglected. When the magnitude of B is increasing to ev×B ~ eErf, electrons can still fly to the opposite plate but with a lower incidence energy. Obviously, the multipaction breakdown threshold can be improved under this situation. And as the magnitude of B continually increasing, the secondary electrons are bounded down to the initial emission surface of these secondaries. The single-side multipaction may be stimulated as the electrons get enough energy from the field during flying. When the hopping frequency Ω of electrons is closing to half of the angular frequency of the field ω/2, the breakdown threshold is the lowest. The discharge threshold increases to some extend as the magnitude increasing and the flying time decreasing. When the magnitude of B is large enough, the flying time is too short to get enough energy and the collision energy is always lower than the first cross over energy of the secondary electron yield of the dielectric material.

It should be mentioned that the accumulated space charge field Edc can be approximated by a saturation model of the electrons on the dielectric plates. The space distribution density of electrons adjacent to the dielectric surface and the magnitude of the DC field are determined.

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