INITIAL STUDIES OF MULTIPACTOR SUPPRESSION VIA TE AND TM MODES*

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Abstract

The formation of multipactor is strongly dependent upon the secondary electron yield (SEY) of a surface, and the emission velocities of the emitted electrons, in addition to the electric field. Since the secondary electron yield (SEY) of a material is dependent upon the kinetic energy and impact angle of the incident electron, we investigate use TE and TM coaxial cavity modes to modify the impacting electron velocities to reduce the average SEY and suppress multipactor, which builds upon our previous work examining TEM modes.

INTRODUCTION

Multipactor [1, 2] is a resonant phenomenon in which an electromagnetic field causes stray electrons to impact a surface, liberating secondary electrons, in such a way that the process can sustain itself. This phenomenon is of considerable practical interest in the design and operation of microwave windows, waveguides, and radio frequency resonant structures.

The formation of multipactor is strongly dependent upon the secondary electron yield (SEY) of a surface contributing to multipactor, since in order to initiate and sustain multipactor, the average number of emitted secondary electrons must be greater than or equal to unity. Multipactor is also dependent upon the system geometry and field excitation, which must be conducive to accelerating electrons into the boundaries at the proper RF phase to enable re-acceleration of the emitted secondary electrons.

When an electron impacts a boundary, the average secondary electron yield (SEY) is determined by the kinetic energy of the incident electron. Figure 1 shows a representative SEY curve. The specific SEY curve used in this present research was generated using Vaughan's model [3] with parameters chosen to match the impact energy location (E_{max}) and peak value (δ_{max}) of Furman's SEY model for copper [4], and is used for all the results presented in this study.

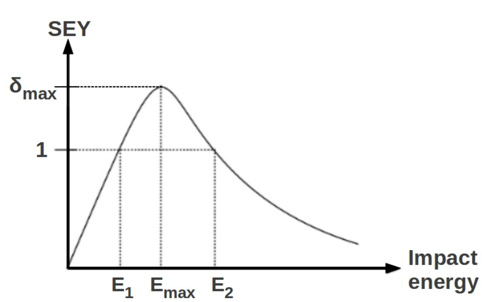

Figure 1: Typical SEY curve.

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SIMULATION DESCRIPTION

Consider a coaxial cavity with conducting sidewalls, inner radius a, outer radius b, and longitudinal length L. The fundamental-mode TEM excitation at angular frequency ω can be parameterized by peak instantaneous voltage V_o and phase θ as $V_o \cdot \cos(\omega t+\theta) \cdot \sin(\pi z/L)$.

In our present research, we defined a=1 cm, b=5.65 cm, and L=1.86 m, and we used Vaughan's SEY model mentioned above. Unless otherwise noted, all secondary electron emission energies are set to zero to avoid the complication of the truly random (although typically low-energy) secondary emission energies. The selected geometrical values will allow a fundamental TEM mode to exist at 80.5 MHz, and the SEY model to yield maximum secondary electrons at $V_o \approx 1000$ V.

Electrons start from rest at the outer wall, and the net SEY is computed as the product of all the single-impact SEY values over 10 simulation steps, where each step is one fundamental mode period or boundary impact, whichever comes first. For each impact, a single simulated secondary electron is emitted and tracked. Only trajectories with at least two boundary impacts within ten fundamental-mode RF periods were considered to have net SEY > 0. The net SEY gives a proxy measure of the presence of the multipactor, since a net SEY < 1 would indicate that multipactor is not sustainable. Figure 2 shows the net SEY for the notional coaxial cavity for electrons starting at z values of 0.2L and 0.5L, where z=0 is defined to be the end of the cavity, and z=0.5L is halfway along the length of the cavity. The net SEY is displayed on a logarithmic scale, anything above 0 denotes a net increase in multipacting electrons. Note that to first order, the effect of changing z merely scales the multipactor voltage axis via the $\sin(\beta_z z)$ dependency.

MULTIPACTOR SUPPRESSION

Multipactor can only be sustained if the average SEY over the multipactor orbits is at least unity. This suggests a novel way to suppress multipactor, via the application of secondary excitation modes which result in the secondary electron impact energy being pushed away from the values where the SEY exceeds unity. Our previous work [5] explored multipactor suppression using an appropriately scaled and phase-referenced 3rd harmonic TEM mode, expressed mathematically as $-3V_o \cdot \cos(3\omega t+3\theta) \cdot \sin(3\pi z/L)$. The results are shown in Fig. 3, and it is apparent that the regions of sustainable multipactor have significantly decreased from the baseline case.

We now examine the use of TM and TE modes for the suppression of multipactor. This initial research examines the lowest order TM and TE modes, namely TM011 and TE011. The TM011 electric (E) and magnetic (H) field components are given by:

$$E_\rho = \frac{j\beta_\rho\beta_z}{\omega\mu\epsilon}\left[AJ'_0(\beta_\rho\rho)+BY'_0(\beta_\rho\rho)\right]\sin(\beta_z z)$$
$$E_\phi = 0$$
$$E_z = \frac{-j\beta_\rho^2}{\omega\mu\epsilon}\left[AJ_0(\beta_\rho\rho)+BY_0(\beta_\rho\rho)\right]\cos(\beta_z z)$$
$$H_\rho = 0$$
$$H_\phi = \frac{-\beta_\rho}{\mu}\left[AJ'_0(\beta_\rho\rho)+BY'_0(\beta_\rho\rho)\right]\cos(\beta_z z)$$
$$H_z = 0$$

and the respective TE011 field components are given by:

$$E_\rho = 0$$
$$E_\phi = \frac{\beta_\rho}{\epsilon}\left[AJ'_0(\beta_\rho\rho)+BY'_0(\beta_\rho\rho)\right]\sin(\beta_z z)$$
$$E_z = 0$$
$$H_\rho = \frac{j\beta_\rho\beta_z}{\omega\mu\epsilon}\left[AJ'_0(\beta_\rho\rho)+BY'_0(\beta_\rho\rho)\right]\cos(\beta_z z)$$
$$H_\phi = 0$$
$$H_z = \frac{-j\beta_\rho^2}{\omega\mu\epsilon}\left[AJ_0(\beta_\rho\rho)+BY_0(\beta_\rho\rho)\right]\sin(\beta_z z)$$

where a cylindrical (ρ, φ, z) coordinate system is assumed, (β_ρ, β_φ, β_z) represent the respective wavenumber components, ω represents angular frequency, μ represents the magnetic permeability, ϵ represents the electric permittivity, J_0 and Y_0 respectively represent 0th-order Bessel functions of the first and second kind, and primes denote derivatives. A and B are geometry-dependent constants which ensure that the tangential E-field goes to zero at the cavity boundaries. Since the electron speeds in our simulations are much less than the speed of light, the TM011 and TE011 magnetic field effect upon electron trajectory is negligible as compared to the electric field.

The plots in Fig. 4 show the net SEY for the same geometry and baseline excitation, but now with an additional mode of TM011 (top plots) or TE011 (bottom plots). The maximum field strength for each of these modes was set to 500 kV/m, which was somewhat arbitrarily chosen because this value is considered a strong but not unrealizable field strength. These modes were phase-referenced such that E_ρ started at zero phase at time=0 for the TM011 case, and E_φ started at zero phase at time=0 for the TE011 case. Additional phase shifts of 120º and 240º for the respective TM011 and TE011 fields were investigated. Although the specific multipactor-stable regions did exhibit some change, no qualitative difference was observed.

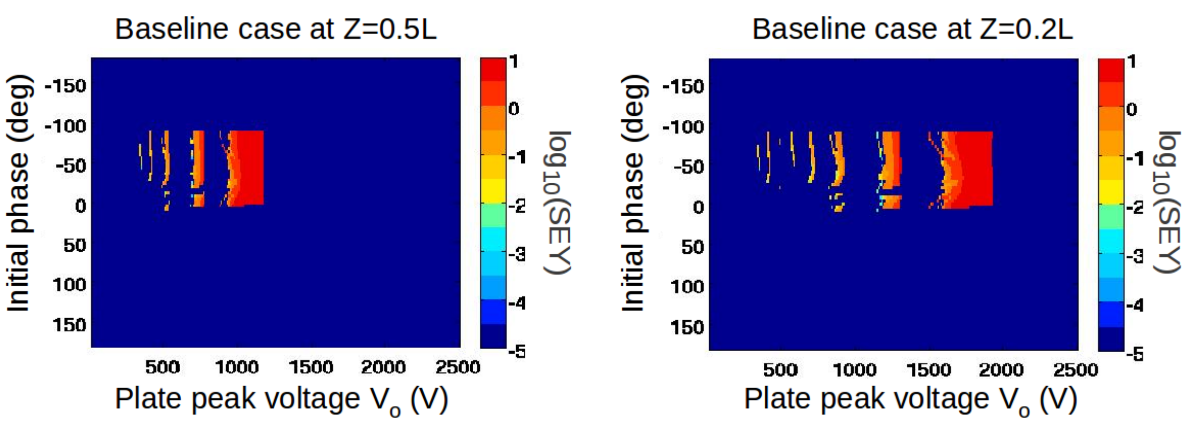

Figure 2: Simulated multipactor sustainability in a notional coaxial geometry, at two different z locations.

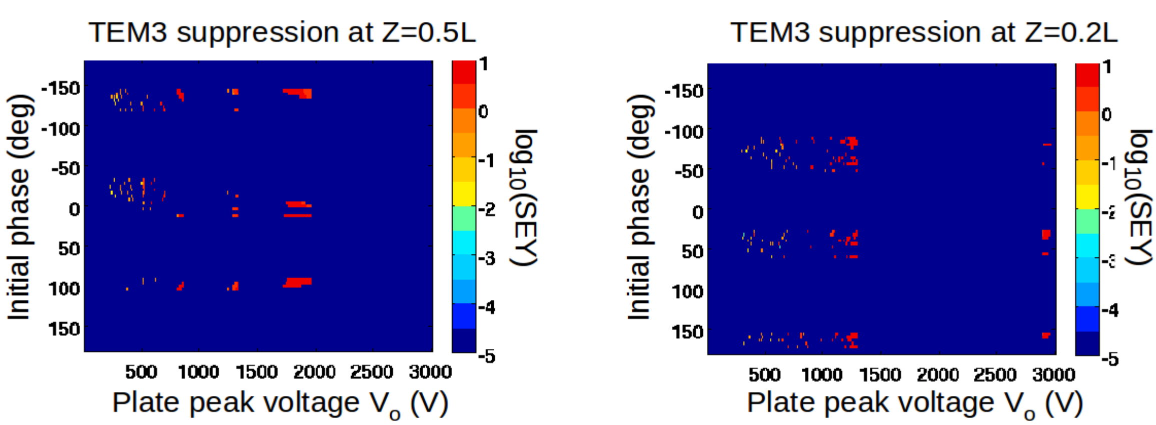

Figure 3: Multipactor sustainability in a notional coaxial geometry, at two different z locations, with a 3rd harmonic TEM suppression signal applied.

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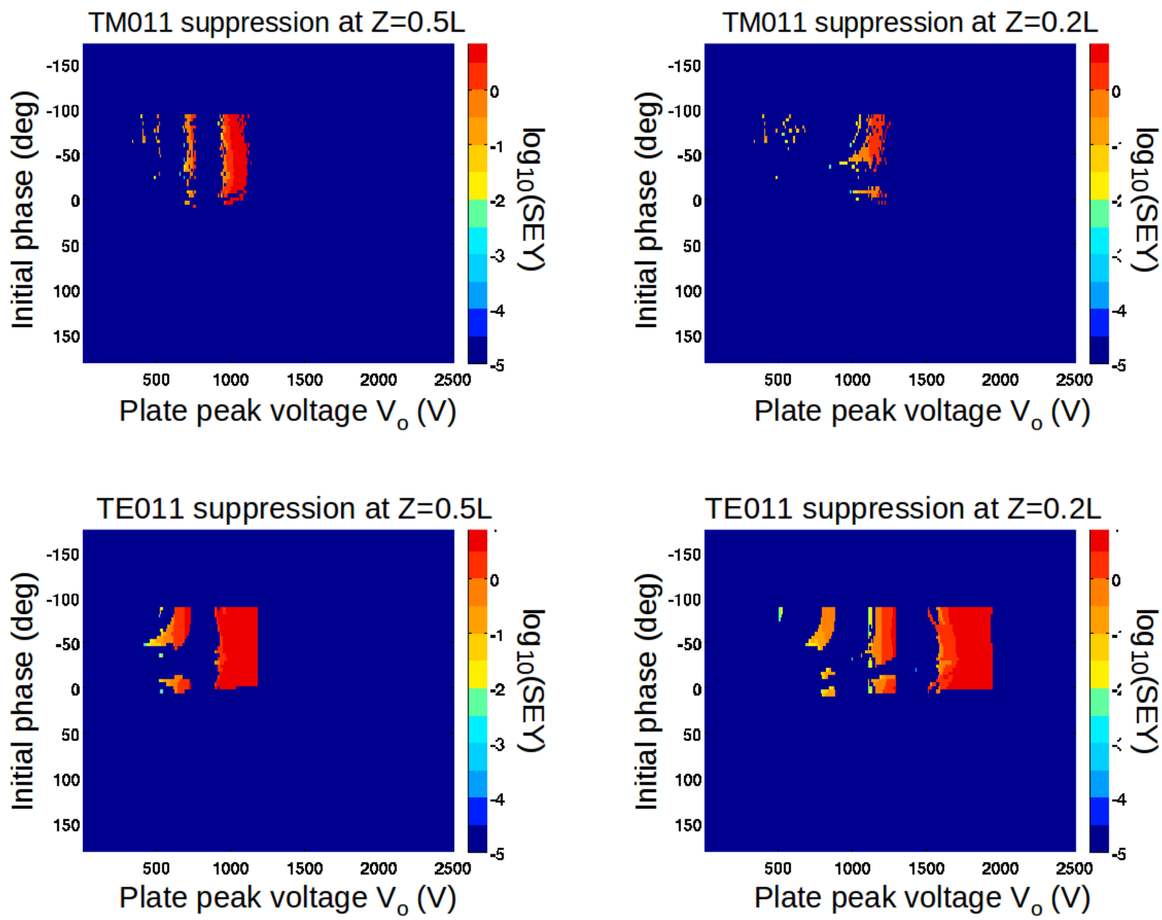

Figure 4: Multipactor sustainability with 500 kV/m TM011 (top) and TE011 (bottom) modes present, at z values of 0.5L (left) and 0.2L (right).

CONCLUSIONS AND FUTURE WORK

The TM011 and TE011 modes explored thus far do not suppress multipactor as much as the 3rd Harmonic TEM mode examined previously. [5] This is mainly attributable to the time scale of the different modes: the baseline TEM mode frequency is at 80.5 MHz, whereas the TE and TM modes considered here are at around 3.2 GHz, resulting in a small periodic perturbation to the overall trajectory of the particles. Additional work [6] presented in a poster at this conference also demonstrates the extreme sensitivity of multipactor simulation to the low-impact energy SEY and the secondary emission energies which are being neglected in the results presented above. Thus future work in this area will also take into account non-zero secondary emission energies.

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