Combined Field Emission and Multipactor Simulation in High-Gradient RF Accelerating Structures

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INTRODUCTION

In high-gradient (HG) RF accelerating structures like the ones used in CLIC [1, 2] is common to have field emission of electrons in the surfaces with highest electric field. The FE current follows the Fowler-Nordheim law [3] and the electrons can be accelerated by the RF fields forming the so-called dark current (DC) [4, 5]. FE is also related with RF breakdown, the vacuum discharge that limits the performance of HG structures.

$$J = a\beta^2 E^2 e^{\frac{-b}{\beta E}}$$

Multipactor (MP) [6] is another kind of breakdown that normally appears in lower field RF components, for example in space applications [7]. This is a resonant process, were electrons couple to RF fields describing synchronized trajectories, and colliding with the material walls, that together with a secondary electron emission (SEE) positive feedback leads to an avalanche. MP has already been analyzed in other HG linacs [8, 9].

In this work, a theoretical study of the MP discharge in the CLIC/CERN cavities is described, by means of CST [10] particle in cell simulations including FE and SEE properties. Discharge is observed at the nominal gradient of 100 MV/m. A future experiment for transversal DC measurements is presented, making use of a modified TD24 CLIC prototype.

FIELD EMISSION AND MULTIPACTOR

The RF cavities used in this work are 12 GHz travelling wave CLIC accelerating structures working in the $2\pi/3$ mode. We focus in the transversal DC of a single cell. Doing particle simulations of the FE electrons, with and without SEE property, we are able to see if MP actually occurs.

There are mainly two different types of CLIC structures. First we have the T24 prototypes, which are made of cylindrical cells, and later the TD24 prototypes, which include damping waveguides for high order mode absorption.

Figure 1 present the electric field magnitude and the particle simulation for both prototypes. One can see how electrons emitted in the left iris travel to the sidewalls and cause multipacting in there.

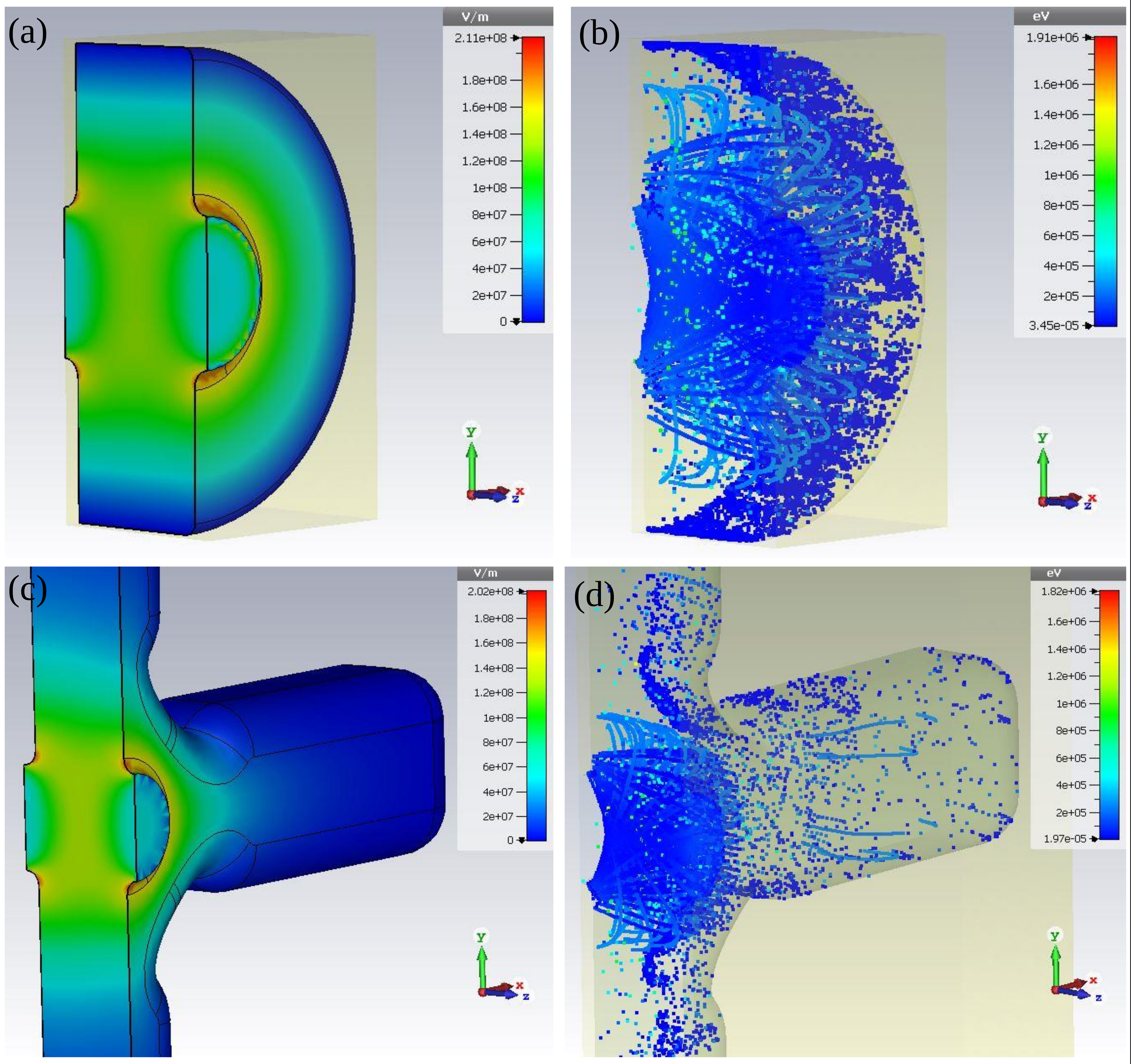

Figure 1: (a) Electric field magnitude in a T24 cell, at 100 MV/m gradient. (b) CST PIC simulation for the same cell. (c) Electric field magnitude in a TD24 cell, at the same gradient. (d) CST PIC simulation for that cell.

The simulation statistics of the T24 are presented in Fig. 2a, whilst Fig. 2b shows the case of the TD24. The total number of electrons is presented in the continuous blue line, showing an exponential growth typical from MP, which causes the simulation to stop.

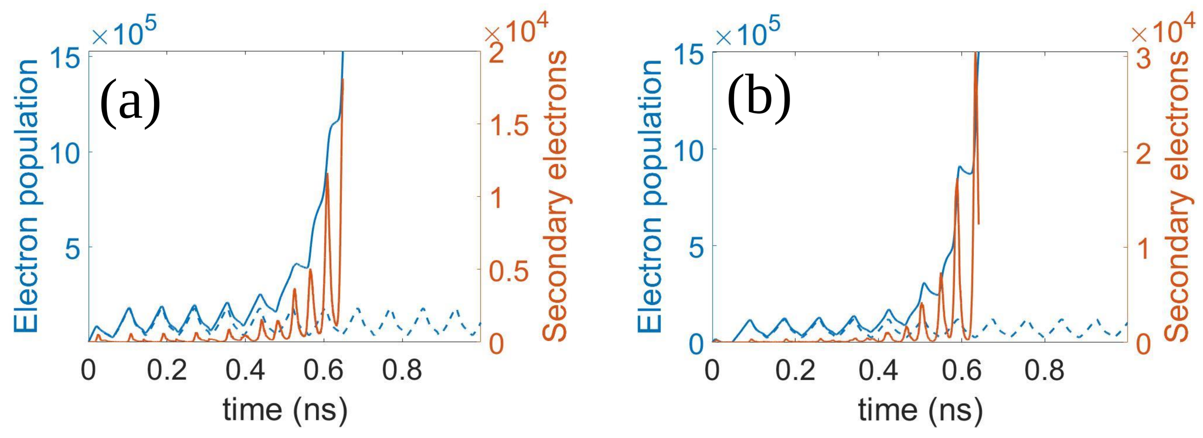

Figure 2: Simulation statistics for the T24 (a), and the TD24 (b): Electron population as a function of time considering SEE (continuous blue) and without SEE (dashed blue). The right axis accounts for the number of secondary electrons created during the discharge (brown).

Figure 3 shows MP trajectories extracted from the T24 simulation. One can imagine that the metal surface is vertically oriented in the right side of the pictures, showing how these electrons bounce and go back to the walls. Figures 2a and 2b show that the secondary electron spikes are separated by half RF period, which leads us to think that the fundamental MP mode is dominating the discharge.

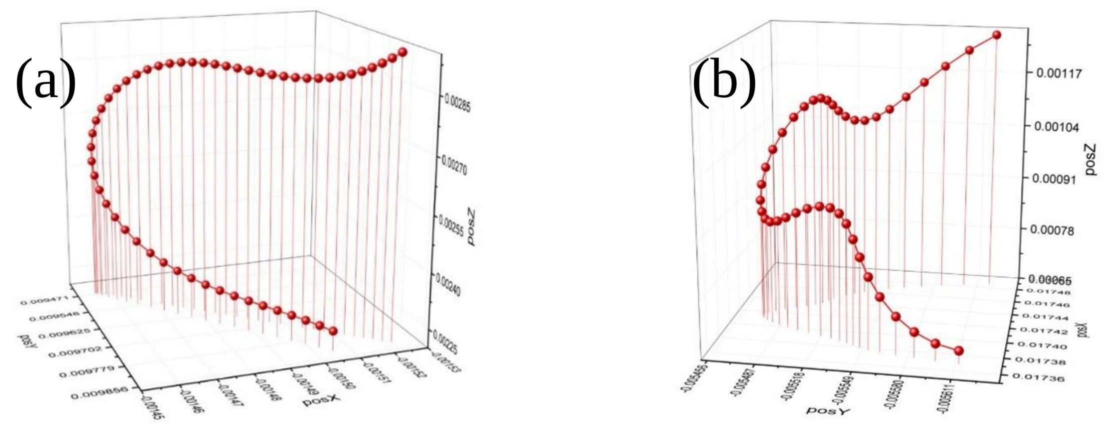

Figure 3: (a) Fundamental mode of the single-surface two-points MP. (b) Resonance of a higher order MP mode, where the RF field changes polarity several times before the electron manage to go back.

FUTURE EXPERIMENT

At this moment no experimental measurements can support this theoretical work because we cannot perform transversal DC measurements in the CLIC cavities that are currently available. Figure 4 shows the mechanical design of a modified TD24 CLIC structure. In this design, the damping waveguides of the central cell have been open to air and new waveguide taper transitions have been brazed, ending in a standard vacuum flange. This design allows the connection of Faraday cups in the four central ports, in addition to the upstream and downstream ports that we have in all CLIC structures.

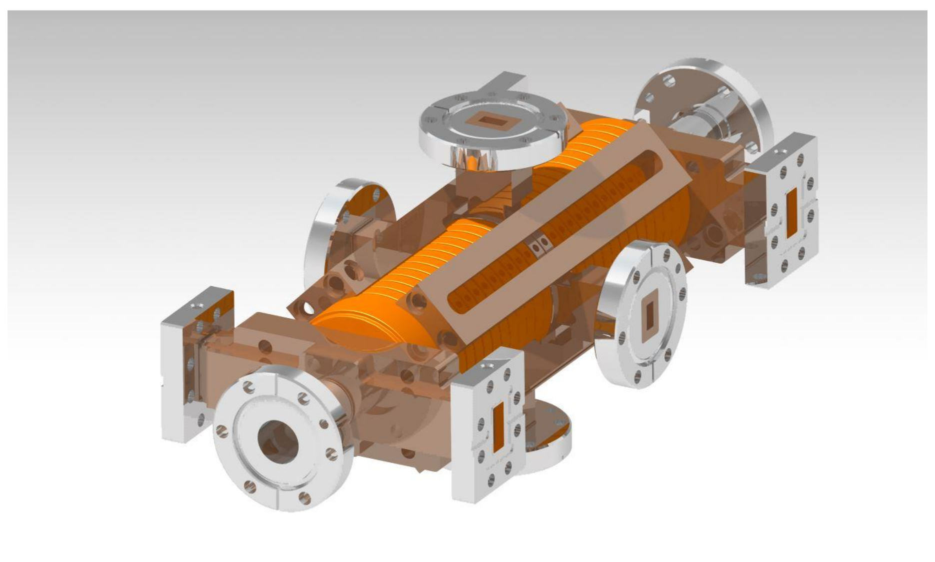

Figure 4: Mechanical design of the modified TD24 CLIC structure for multipactor and breakdown analysis.

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