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DESIGN OF A HIGH-GRADIENT THz-DRIVEN ELECTRON GUN*

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Abstract

We present the design of a high-gradient electron gun. The goal of this gun is to generate relativistic electrons using GV/m accelerating fields. The initial design is a standing-wave field-emission gun operating in the π-mode with a cavity frequency of 110.08 GHz. A pulsed 110 GHz gyrotron oscillator will be used to drive the structure with power coupled in through a TM_{01} circular waveguide mode. The gun is machined in two halves which are bonded. This prototype will be used to characterize the electron beam and study RF breakdown at 110 GHz.

INTRODUCTION

The development of high-gradient accelerators is motivated by a need for new sources of high-energy particles. Applications including ultrafast electron diffraction (UED) and next-generation colliders require high-brightness electron sources. Using high-gradient technology to create these sources allows for improved performance with a smaller footprint than current accelerators.

In normal-conducting RF accelerating cavities, RF breakdown limits the achievable gradient. Studies of RF breakdown in copper structures have been conducted at X-band [1–5], Ku-band [6], and Ka-band [7–9], providing valuable insight into how RF breakdown behavior varies with frequency. Recent work has extended these studies to the mm-wave range [10–13]. Together, the results of these studies indicate scaling to THz frequencies may provide a pathway to GV/m accelerating gradients.

This work presents initial designs for an electron gun based on high-gradient mm-wave accelerating structures. The field emission-type gun will utilize 110 GHz cells to ultimately produce 1 MeV electrons with GV/m accelerating fields.

ELECTRON GUN OVERVIEW

We have developed two W-band standing wave gun designs. The first is a 2.5 cell structure with similar dimensions to W-band structures developed for high-gradient testing (see [12–14]). The second design uses two smaller cells with no half cell. Both structures support TM_{01} π-mode acceleration at roughly 110.08 GHz and use on-axis coupling from a TM_{01} circular waveguide mode. The guns will be fabricated from copper using split-block machining. Substantial work has already been performed to study the feasibility of applying the split-block process to high-gradient THz structures [15].

Both guns are designed to use a small diamond pyramid as the field emitter. The pyramid is part of an array of tips on a diamond square which is brazed to a metal substrate. These diamond tip arrays have been studied as field emitters at 1.3 GHz and optical wavelengths [16–18]. A scale model of an example tip array is shown in Fig. 1.

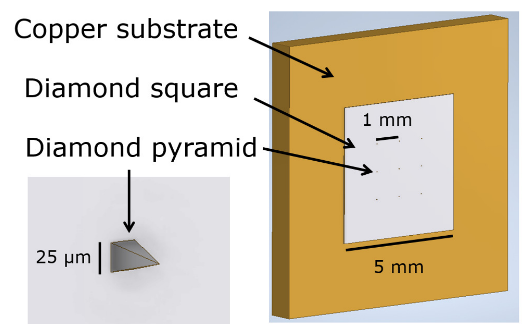

Figure 1: Model of a 9x9 tip array with 1 mm spacing and 20 μm pyramids on a 1 cm copper substrate.

The structures will be tested using a 110 GHz gyrotron. The gyrotron beam power is coupled into the structure through a Guassian horn followed by a mode converter. Details of this test setup are discussed in [12, 13]. Currently the gyrotron supplies up to 1 MW of RF power, but future work will include the development of a pulse compressor to reach higher power.

PROTOTYPE SIMULATIONS

Full 2.5 Cell Structure

The 2.5 cell structure is tuned such that the on-axis electric field is highest in the half cell. The diamond pyramid sits at the end of a short beam pipe in order to limit the surface fields on the tip. The structure was simulated in HFSS [19] and the field distribution of the design mode is shown in Fig. 2. The frequency of the mode is $f = 110.0775$ GHz with $S_{11} = -39.5$ dB. A simple single particle model of acceleration predicts that this structure will produce order MeV electrons with 2.75 MW of input power. A plot of the sampled electric field and the resulting particle energy is shown in Fig. 3.

Two Cell Structure

This structure eliminates the half cell and uses the iris of the first cell to keep the diamond tip in a lower field region.

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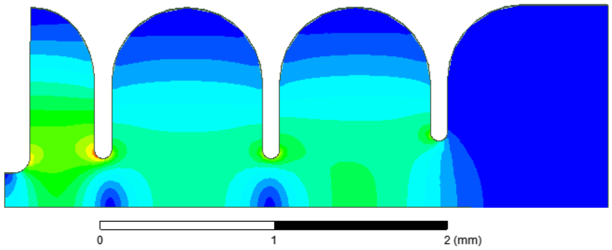

Figure 2: Normalized electric field distribution for the TM_{01} π-mode. The maximum field on axis is 838 MV/m and the peak surface field is 1.86 GV/m.

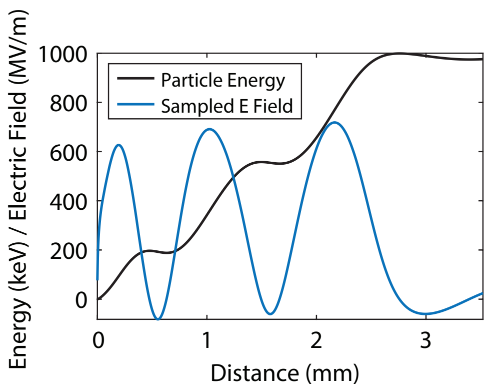

Figure 3: Sampled on-axis electric field (blue) and the resulting change in electron energy (black) for 2.75 MW of input gyrotron power and a launch phase of 60 degrees.

The simulated field distribution shown in Fig. 4. The cells are tuned such that the on-axis field is higher in the first cell. Single particle calculations predict this design will perform well with lower input power, allowing it to be tested without a pulse compressor on the 110 GHz gyrotron. The predicted electron acceleration for 1 MW of input power is shown in Fig. 5. The frequency of the mode is $f = 110.0765$ GHz with $S_{11} = -18.4$ dB.

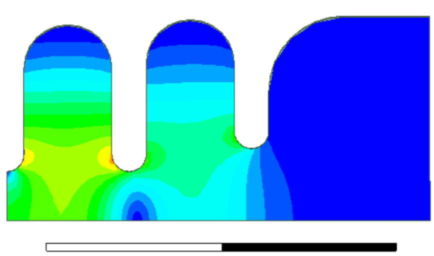

Figure 4: Normalized electric field distribution for the TM_{01} π-mode. The maximum field on axis is 706 MV/m and the peak surface field is 1.18 GV/m.

PROTOTYPE FABRICATION

Initial fabrication work for the 2.5 cell prototype has begun. The structure will be direct machined in a split-block configuration and then brazed. Figure 6 shows a 3D model

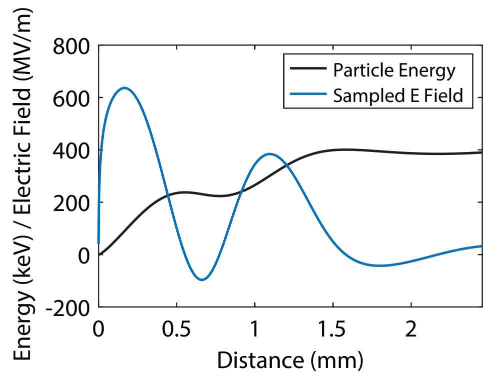

Figure 5: Sampled on-axis electric field (blue) and the resulting change in electron energy (black) for 1 MW of input gyrotron power and a launch phase of 60 degrees.

of one half of the block, including the mode converter and Gaussian horn. The substrate holding the diamond tips will be attached to the assembled block. Fabrication is under-

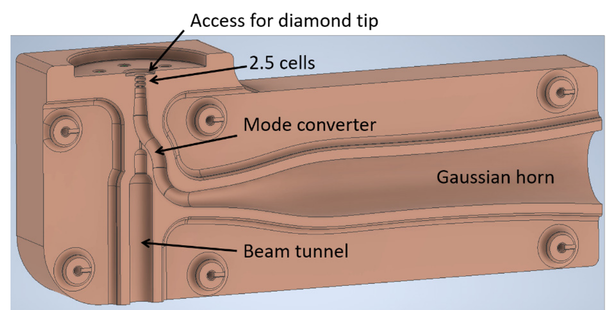

Figure 6: Model of one half of the split-block 2.5 cell prototype. The diamond tip substrate will be attached to the top of the block when the two halves are assembled. The cells, mode converter, Gaussian horn, and electron beam tunnel are indicated.

way on diamond tip samples consisting of arrays of 5, 15, and 25 μm pyramids on copper and molybdenum substrates. These samples will be used to study the performance of the diamond at 110 GHz.

CONCLUSION

We have created two prototype designs for a field-emission electron gun at 110 GHz. The 2.5 cell structure is designed to produce 1 MeV electrons with 2.75 MW of input power, while the 2 cell structure is designed to produce 400 keV electrons with 1 MW of input power. The field-emission source will be a μm-scale diamond pyramid. Initial fabrication work is underway for the diamond tips and 2.5 cell structure. Future work will include electron beam simulations, fabrication of the 2 cell structure, and testing of the structures using a 110 GHz gyrotron.

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