MODELING THE DEVELOPMENT AND MITIGATION OF CHARGE ACCUMULATION FOR PHOTO EMISSION ELECTRON GUNS*

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Abstract

One potential problem with the operation of photo emission electron guns is the potential for charge to accumulate on the emission surface depending on how the biasing voltage is applied to the gun. If the voltage is applied away from the emission surface there is the potential for charge to accumulate on the emission surface since not all electrons will necessarily be emitted. This charge accumulation may affect the gun operation by reducing the accelerating field in the gun. We report on simulations that demonstrate this potential issue as well as simulations that test a potential solution where a secondary voltage is applied periodically to clear the accumulated charge.

INTRODUCTION

New design for photoinjectors has been proposed that will address the need for high current, high brightness beams for future particle accelerators [1, 2]. The design takes a primary electron beam from a conventional photocathode which is accelerated to a diamond window. The diamond window consists of a layer of diamond followed by a high-vacuum gap with an applied voltage across the window. The primary electrons scatter in the diamond generating cascade of secondary electrons. The electrons drift across the diamond where most of them are emitted into the vacuum gap and then into the accelerating cavity of the gun.

Since not all of the electrons are emitted from the diamond surface charge can build up at the diamond/vacuum interface. If enough charge builds up the field in the diamond can be shorted out preventing further electrons from drifting across the diamond. Experimental studies have shown for a primary electron beam whose pulse length is long enough there is a drop in the emission gain for the cathode [3]. It is believed that this drop off is due to electrons accumulating at the surface of the diamond reducing the electric field in the diamond.

We ran a series of simulations with the Vorpal multiphysics code [4] to study the process of charge accumulation in the diamond window from first principles. These simulations can be challenging due to the relative long time scales of the primary electron pulse length relative to the electron scattering rates in diamond. However, we were able to demonstrate the build up of charge at the surface and look at possible ways to clear the charge with a second voltage applied after the primary electron pulse has passed.

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SIMULATIONS

We use the parameters given for the diamond window from Ref. [3] as a starting point for our simulations. To be able to complete the simulations in a reasonable amount of time the physical size was scaled down by a factor of 100 giving us a diamond thickness of 3 microns and the thickness of the full window (diamond plus vacuum gap) of 5.5 microns. Similarly the beam radius was reduced by a similar amount to 4 microns. We reduce the applied voltage by the same factor of 100 to keep the same electric field magnitude giving us a voltage of 30 volts across the diamond window.

We performed 3D simulations of the diamond window. The simulation domain was 5.5 microns in the direction of beam propagation and 10 microns in the transverse direction. We used Vorpal's electrostatic solver to solve for the electric field generated by the various applied voltages as well as the fields generated by the electrons themselves. The electrons are represented using the particle-in-cell (PIC) method with the addition of recently developed scattering models for electron propagation in diamond [5].

Since the time scales needed to cover the pulse width from from Ref. [3] are very long compared to the time scale needed to resolve the highest scattering rate for diamond we increased the beam current so the charge will accumulate faster in the simulations. We also apply a fully reflecting boundary condition for the particles at the diamond/vacuum interface effectively setting the emission probably at the surface to be zero. We run the simulation for the twice the pulse width so we can study the accumulation of the charge while the pulse is on and the dissipation of the charge after the pulse has passed.

Charge Accumulation Simulations

In the first simulation we maintain the voltage across the diamond window while the beam pulse is on. Once the beam pulse has passed we shut off the voltage across the diamond window. Figure 1 shows a scatter plot of the macroparticle positions projected into a plane with one direction along the direction of beam propagation in the simulation shortly before the voltage is shut off. This plot shows the charge accumulating at the diamond/vacuum interface.

In Figure 2 the electric field perpendicular to the diamond surface at the diamond/vacuum interface is plotted versus time. The magnitude of the electric field drops as more charge is introduced to the diamond and begins to accumulate at the diamond/vacuum interface. Eventually the field drops to zero as enough charge has accumulated to short out the field. Once the pulse has passed and the voltage across the diamond window is shut off the electric

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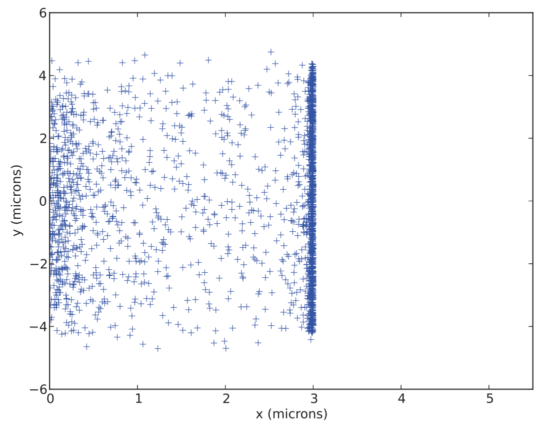

Figure 1: Macro-particles just before voltage across diamond window is shut off.

field changes sign as it is now the space charge of the electrons that dominates the electric field. The electrons that have now accumulated on the diamond surface are pushed back off by space charge forces. As the electrons leave the surface the magnitude of the electric field drops again but it begins to level off before reaching zero. This implies that a steady state may be reached or the rate of decrease could be slow enough that the charge accumulated may not be cleared before the next beam pulse hits the window negatively impacting the operation of the amplifier.

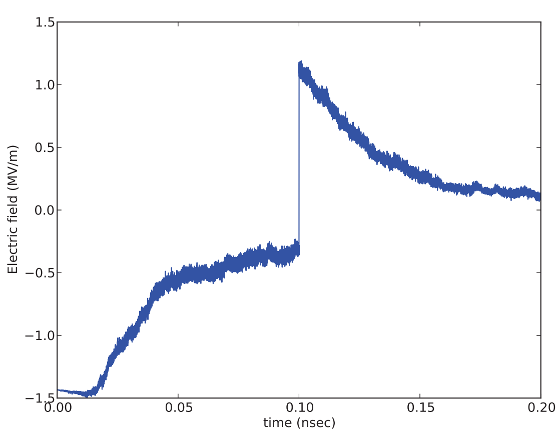

Figure 2: Electric field at diamond surface versus time.

Charge Clearing Simulations

A second simulation was run where after the beam pulsed as passed and the voltage across the diamond window is shut off a new voltage of the same magnitude is now applied parallel to the diamond surface. This produces an electric field parallel to the diamond surface that speeds up the clearing of the accumulated charge. This causes the charge transport to move parallel with the diamond surface and extract the electrons from the transverse sides of simulation. Figure 3 shows the number of macro-particles versus time for the original simulation (in green) and the new charge clearing simulation (in blue). The initial charge accumulation is the same for both simulations but the charge dissipates faster with the clearing voltage applied.

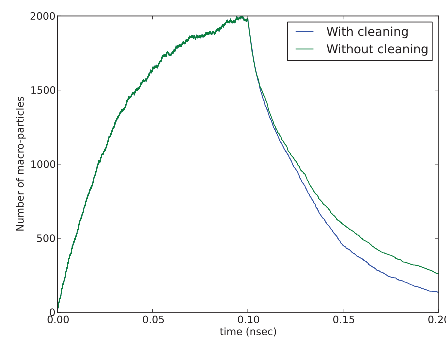

Figure 3: Number of macro-particles versus time for simulations with and without clearing voltage.

CONCLUSIONS

We have qualitatively shown that simulations can be used to study the process of charge accumulation in diamond amplifier designs proposed as part of new designs for photoinjectors. Both the build up and dissipation of the charge can be modeled and potential solutions to the charge accumulation can be studied.

Future plans include the addition of models for surface emission at the diamond/vacuum interface. This will better model both the process of charge accumulation and the process of charge dissipation after the voltage has been shut off since charges can now escape though the diamond/vacuum interface. Development work will be done to provide further flexibility in the particle boundaries so the clearing voltages can be applied directly to the diamond/vacuum interface.

Efforts will also be pursued to bring the simulation parameters closer to those found in a realistic device. These will include making use of HPC resources to allow for larger simulation sizes. Initial tests have shown that the diamond scattering may not require fully resolving the scattering rates since multiple scatter events can happen in a time step.

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