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STUDY OF PHOTOCATHODE SURFACE DAMAGE DUE TO ION BACK-BOMBARDMENT IN HIGH CURRENT DC GUN*

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Abstract

In high current DC gun, GaAs photocathode lifetime is limited by the ion back-bombardment. While gun operation ions are generated due to the impact of electrons with residual gas molecules. These ions accelerate back towards the cathode and remove the activation layer's material from the photocathode surface, thus causing the photoemission performance degradation. We have developed an object-oriented code to simulate the ion generation due to dynamic gas pressure and ion trace in the electromagnetic field. The pressure profile varies from cathode position towards the transfer line behind the anode, which signifies the importance of dynamic simulation for ion back-bombardment study. In our surface damage study, we traced the energy and position of the ions on the photocathode surface and performed the Stopping and Range of Ions in Matter(SRIM) simulation to count the number of Cesium atoms removed from the surface due to single impact. Cesium atom removal is directly related to the photocathode Quantum Efficiency(QE) decay. Our new dynamic simulation code can be used in any DC gun to study ion back-bombardment. We have used this new code to better understand the ion generation in prototype BNL HVDC gun, and we also estimated the normalized QE decay due to ion back-bombardment.

INTRODUCTION

The Quantum Efficiency(QE) of GaAs photocathode in DC gun degrades mainly due to ion back-bombardment. While extracting electron beam from the photocathode, the emitted electron collide with the residual gas molecule and ionize the gas species. The dominant gas species in DC gun is hydrogen, as a result the ions generated are hydrogen ions. Ions generated in between DC gap could have wide range of energy when hit back on the cathode surface, and it depends at which position ions are created along the beam trajectory. While ions generated beyond the anode position could still trap in the beam and drift towards the dc gap, and hit photocathode with full potential of the maximum gun voltage [1]. GaAs is usually activated by depositing a thin layer of Cesium and Oxygen on photocathode surface which produce Negative Electron Affinity(NEA) state. Ions of sufficient energy could sputter away the activation layer material such as Cesium and Oxygen from the photocathode surface. Implantation also occurs, which creates vacancies and interstitials that negatively affect the photoemission [2]. Once photocathode is activated, the QE depends on surface Cs loss, chemical poisoning and lattice damage. In our study we have assumed that, the amount of Cs loss is directly proportional to the photocathode QE decay.

BEAMLINE AND PRESSURE PROFILE

To study ion back bombardment all the existing models consider constant pressure from cathode position to the beamline. However, while DC gun is in operation, dynamic pressure can vary substantially from main gun chamber to the beamline. Therefore, to understand the cathode damage mechanism due to ion-back bombardment we need to consider the variable pressure profile from cathode position to the beamline. In our analysis we have considered Brookhaven National Laboratory(BNL) 350 kV DC gun geometry [3], and simulated the pressure profile from anode position to the beamline. Pressure profile is totally dependent on specific gun geometry, pumping arrangement and pumping rate. Simple modification of gun geometry, or pumping parameters can change the outcome of the pressure profile. In our simulation we have used molflow+ [4] to simulate the variable pressure profile from cathode position to the beamline. In figure 1 molflow+ model and pressure profile is presented.

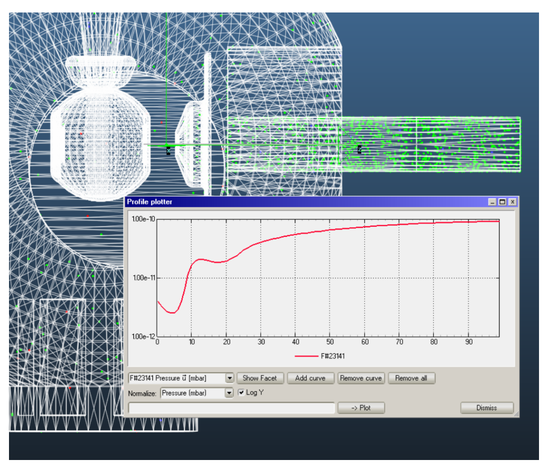

Figure 1: Vacuum model of the BNL 350 kV DC gun and corresponding pressure profile from cathode position towards the beamline. In molflow+ pressure is presented in mbar unit.

DYNAMIC PRESSURE CODE DEVELOPMENT

We used General Particle Tracer(GPT) [5] code to simulate the ion back-bombardment on cathode surface in DC gun. The ionization rate as a function of kinetic energy can be written as, $R(E) = I\sigma(E)\rho\Delta z$. Where σ is the ionization

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cross section for electron on H_2, I is the beam current, and ρ is the gas density. Gas density, $\rho = 3.54 \times 10^{22} \times P$[torr]. For constant current and gun voltage, ionization rate is basically proportional to the pressure. If pressure P increase twice, ion generation will increase twice. This validates the necessity of dynamics pressure code development. We have developed an ionizer element named as "ionizerv" [6] which can take into account of dynamic pressure profile along the beamline. "ionizerv" element is used in GPT to track electron along the beamline, and based on electron energy, scattering cross section, and residual gas pressure ions are generated on every location along the beamline. In the second run, ions generated at different location are accelerated back towards the cathode, and their position and energy is recorded on the cathode plane.

ION BACK-BOMBARDMENT ON GaAs PHOTOCATHODE

From the GPT simulation, each ion position and momentum are known on photocathode surface. We have performed Stopping and Range of Ions in Matter(SRIM) [7] simulation to study the impact of H_2^+ ions on GaAs photocathode. SRIM is a group of software to calculate the interaction of ions with matter. The core of SRIM program is Transport of Ions in Matter(TRIM). For the maximum QE of photocathode, the activation layer thickness is usually around 10Å. In TRIM window we have considered 10Å thickness of Cs-O activation layer, and 1 μm thickness of GaAs layer. Total number of ion considered for each simulation is 0.5 million. For projected range calculation we have considered "Detailed Calculation with Full Damage Cascades" in TRIM. Projected range is defined as depth at which bombarded ion has peak concentration.

In Figure 2 we have showed the impurity concentration of 50 keV ions on GaAs photocathode. The Y-Ordinate unit is (Atoms/cm^3)/ (Atoms/cm^2). When one multiply Y-Ordinate by an implantation dose (ions/cm2), will get the true impurity concentration in units of (atoms/cm^3). From graph we see that the projected range of 50 keV H_2^+ ion on GaAs is around 4300 Angstrom. The standard deviation of ion distribution is known as straggle, which is a measure of profile spreading along the normal direction. In Figure 3 we have plotted the range of ions and straggle on GaAs photocathode. Energy of ion considered is 500 eV to 350 keV to match the ion energy of Brookhaven National Laboratory 350 kV prototype DC gun.

To find out sputtering yield of Cesium and Oxygen from the activation layer due to ion back-bombardment we used "monolayer collision step" in TRIM, which is more suitable for sputtering calculation. Sputtering yield is the number of atoms removed from the surface due to one ion impact. Sputtering is dependent on the energy of the incident ion, angle of incidence and mass. Electron impact ionization with Hydrogen molecules can create both H^+ and H_2^+ ion. However scattering cross section of H_2^+ is quite higher than the H^+ ion [8]. For simplicity in SRIM simulation we have

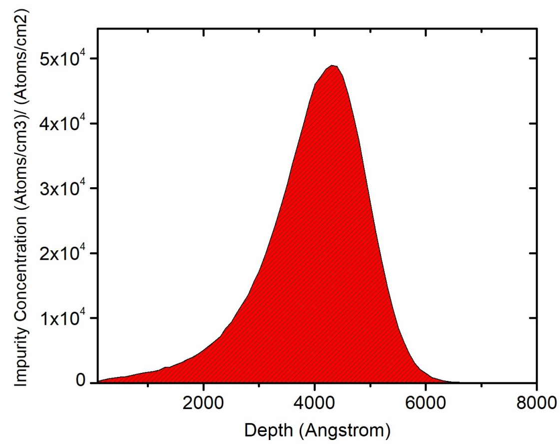

Figure 2: Impurity Concentration due to ion back-bombardment of 50 keV H_2^+ ion on GaAs.

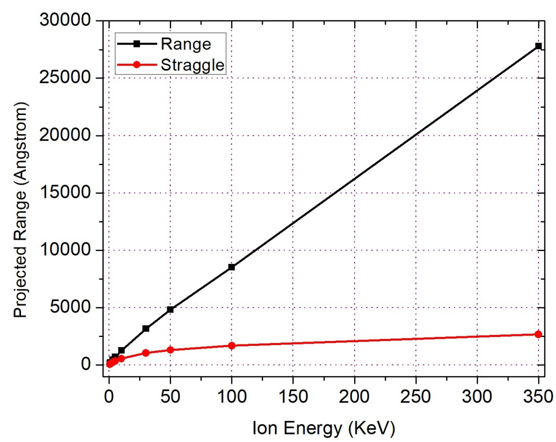

Figure 3: Projected range and straggle of H_2^+ ion GaAs Photocathode. Ion energy considered is from 500 eV to 350 keV.

considered H_2^+ ion only. Sputtering of activation layer material Cs and O is calculated for ion energy ranging from 200 eV up to 350 keV. In Figure 4 we have plotted sputtering yield of Cesium due to ion back-bombardment. Ion impact on GaAs also sputter away Ga and As atoms, however this effect is insignificant compared to the sputtering of Cs and therefore is not presented here. From the graph its evident that low energy ions, having energies between 500 eV to 5 keV causes more damage to the activation layer. High energy ion causes lower sputtering of Cesium and Oxygen. However high energy ions create more vacancies than low energy ions. Thus high energy ions contribute to the lattice damage by creating vacancies and interstitials. Details of the lattice damage are out of scope of this paper.

MAPPING THE PHOTOCATHODE QUANTUM EFFICIENCY

Ion back-bombardment, cathode heating due to laser illumination and chemical poisoning - all contribute to the cathode QE degradation. In our simulation we assumed Cesium loss from the cathode surface is the main cause of QE

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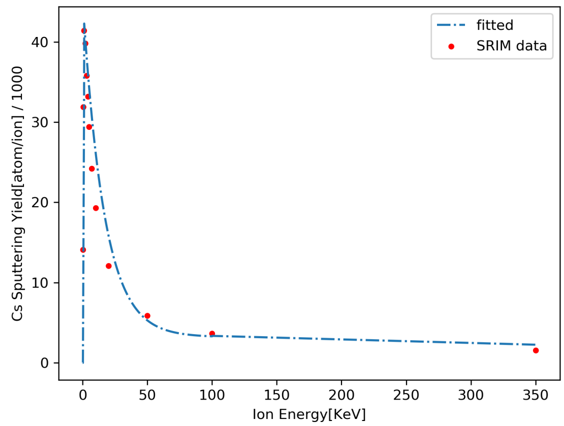

Figure 4: Sputtering yield of Cs due to ion back-bombardment. The red dot is SRIM sputtering data for individual ion energy. Fitted curve is later used for photocathode QE degradation map.

degradation. From dynamic pressure code and GPT simulation we know ions position and energy on photocathode. From SRIM simulation we know number of Cesium atom removed due to ion impact. From this two results we can find normalized photocathode QE due to one bunch ion impact. If no Cesium is removed at a certain grid, the normalized QE equal 1. Whereas maximum Cs loss corresponds to zero QE at a certain grid. Though low energy ions mostly contribute towards surface damage, high energy ions are highly concentrated at the Electrostatic Center(EC) of the photocathode. Thus the overall QE degradation per grid, at EC due to high energy ion is more damaging than the low energy ions at laser illumination area. High energy ions can also significantly increase the local temperature of the photocathode at EC, and facilitate Cs removal. Though temperature induced Cs loss is not considered here for simplicity. In figure 5.a we see the ions map on photocathode surface. All red dots are low energy ions at laser illumination area and green dots are high energy ions mostly located at EC. Figure 5.b represents the QE map due to ion back-bombardment. We see that EC is highly damaged due to the impact of high energy ions densely located at EC. We have considered both offset laser illumination and offset anode position and studied cathode damage due to ion back-bombardment. For simplicity here we have only presented 6 mm laser offset illumination scenario. Details of the offset anode scheme is discussed elsewhere [9].

SUMMARY

We have developed a dynamic pressure code which generates ions based on variable pressure profile along the beamline. Ions position and momentum are mapped on photocathode surface. SRIM simulation is performed to know Cs atom removal due to impact of ions on cathode. Based on ion energy and Cs atom removal from activation layer we have presented QE degradation of GaAs photocathode.

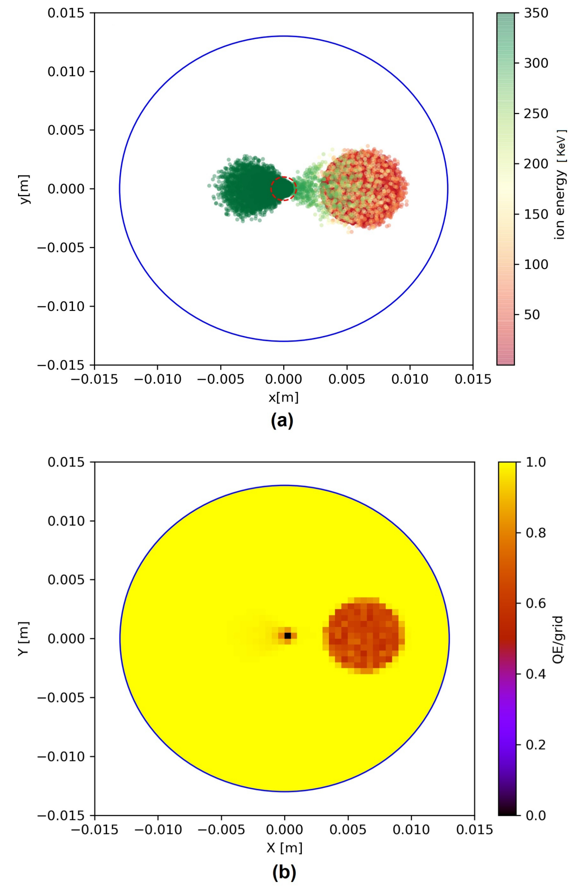

Figure 5: a) represents the ions map on photocathode surface, while b) represents the QE map after ion back-bombardment.

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