HIGH-VOLTAGE TESTING FOR A HIGH-CURRENT ELECTRON GUN*

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Abstract

Cornell University has designed an Energy Recovery Linac (ERL) X-ray facility, necessitating high-brightness electron beam emittance to be provided by the injector. This has posed a continuing technical challenge in the design and contruction of a DC photoemission gun, which is intended to give 100 mA average beam current in a 1300 MHz CW bunch train (77 pC/bunch), as well as to operate at up to 750 kV cathode potential. Construction experience in light of difficulties in meeting the injector requirements will be described. Additionally, in a separate but related topic of interest, the application of Fowler-Nordheim theory to photoassisted field emission is discussed.

INTRODUCTION

The electron gun for the ERL faces many challenges. Cornell University's program to develop a high-performance injector (see Fig. 1) is aimed toward meeting specific requirements which have been reported elsewhere [1]. The source of electrons is the DC photoemission gun which is used with a GaAs cathode. The beam line exits the cathode assembly and travels through focusing solenoids, and then into a normal conducting buncher cavity. The beam then is accelerated inside a cryomodule composed of five superconducing RF cavities, and then into diagnostics, which permit detailed characterization of the beam. It is then disposed of in a dump.

The GaAs photocathode, which is the source of the electrons, is kept under vacuum. The cathode wafer is mounted on a puck and slid into the electrode, permitting easy replacement of the wafer, a process aided by two bellows, one corresponding to one plane of motion and the other to a second. These act like hands, moving wafers in and out of the electrodes. Before a wafer can be inserted into the electrode, it must be cleaned, which is done by heating it and exposing it to hydrogen. The entire process of replacing the cathode wafer takes approximately half an hour, and must be done roughly once a week when the gun is run at 100 mA. Cathode lifetime is limited by several factors, one of which is that the beam can ionize residual gas molecules not removed by the vacuum, with these ions being accelerated back toward the cathode surface, a process known as ion back-bombardment.

A photoemission gun is used rather than a thermionic electron gun, which generates electrons when a wire, filament, or cathode is heated to a very high temperature. A photoemission gun produces electrons as a byproduct of the photoelectric effect, and permits a higher level of control over the beam than a thermionic gun. Further, a photoemission gun has a higher performance, producing a beam
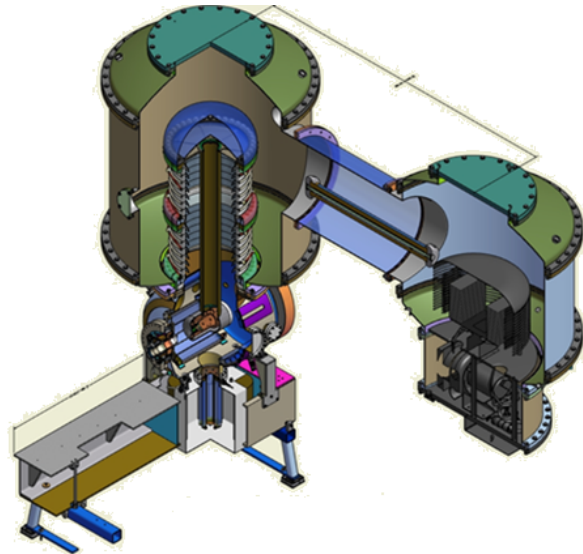
Figure 2: Cutaway view of the mark II gun.

line with low emittance. This low emittance is important to reducing space charge effects, and generating x-rays usable on a nanoscale.

CONSTRUCTION AND TECHNICAL ISSUES

The current DC photoemission gun is limited by field emission, which has resulted in damages. The mark II design (see Fig. 2) incorporates larger insulators, whose separation helps decrease the electric field present in the interior. Cu guard rings populate the insulators, permitting unwanted field emitted electrons to strike them and conduct through to the exterior, at which point they are grounded (see Fig. 3). There is a resistor between each layer, which is used to drain off the charge on the layers. If the resistors were not all connected electrically then the rings would charge up, eventually charging enough that the rings could field emit to the insulators. This guard ring design prevents desctructive levels of electric charge from building up and eventually punching through the insulators.

Cleaning

Components have to be very clean to achieve a good vacuum, with the vacuum itself maintained at 10-12 torr. This high vacuum is employed to increase the photocathode lifetime, removing particles to prevent ion-backbombardment or chemical reactions on the surface of the cathode, which reacts negatively with oxygen, causing it to lose its negative electron affinity. Both ion pumps and non-evaporable getter (NEG) pumps are used to remove particles from the
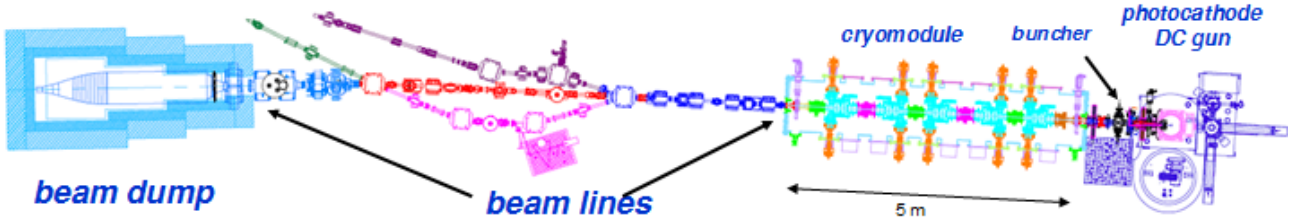
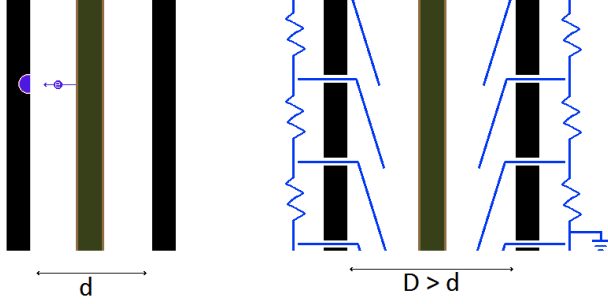Figure 1: Diagram of the Cornell ERL injector prototype.

Figure 3: The mark I electron gun's insulator design (left) suffered damages from field emission, shown as an electron field emitting from the stalk and landing on the interior of the insulator. The mark II electron gun (right) is designed to prevent such damages.
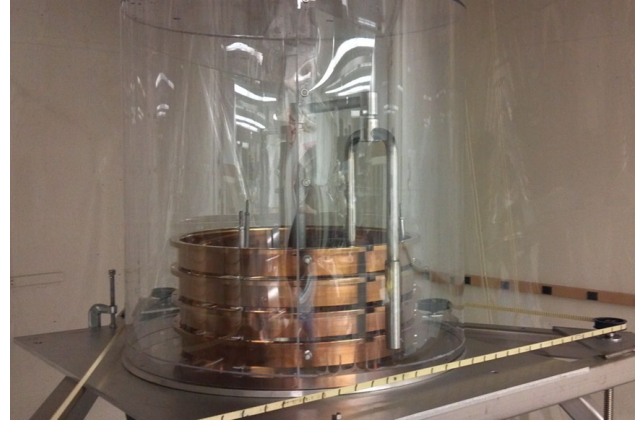

Figure 4: Performing a high pressure rinse on the protection rings, which go on the top and bottom of an insulator.

interior of the gun, which is counteracted by outgassing in the materials. Methods of cleaning components included blowing them off with nitrogen gas, performing high pressure rinses, using chemical baths, double-bagging them and opening them only inside the clean room, and wearing clean room suits to prevent outside contamination. Each component was cleaned using soap and water to remove dust and large particles, and then scrubbed with alcohol to remove fingerprints and other oils. Then the high pressure rinsing process was used, which involved hosing each part with clean, deionized water at 1000 PSI (see Fig. 4).

THEORY

The lifetime of the photocathode is the greatest challenge currently faced due to its chemical reactivity and degradation due to ion-backbombardment. Further, the cathode structure can field emit, leading to insulator punchthrough and vacuum leak [2]. Field emission prevents higher voltages from being applied, ultimately limiting the performance of the ERL itself, as higher voltages would provide a greater initial acceleration of electrons and thus lower emittance. Thus, to better understand field emission, it is of importance to consider the general Fowler-Nordheim equation defined

$$I = Aat_N^{-2}\Phi^{-1}F^2 e^{\frac{-bv_N\Phi^{3/2}}{F}}, \qquad (1)$$

where I is the emission current, a and b are universal constants, phi is the local work function, F is the external electric field, A is the area of emission, and v and t are functions of the Nordheim parameter. If the work function and the external electric field applied are known, current density can be found and compared. The problem with the Fowler-Nordheim equations is that unrealistic assumptions must be made to apply it to data pertaining to the gun. One of these assumptions is that there is only one field emitting location on the surface, and that it is very small, around the size of an atom, meaning that this one atom has a very high current density. It must also be assumed that a constant work function is present throughout the material, which is also unrealistic. In order to make Fowler-Nordheim agree with physical reality, a value called beta is used, which is the field enhancement factor, and which appears in the F term [3-7]. This enhancement factor corrects for surface roughness, which is accurate if the surface has whiskers. However, observed roughness of the GaAs cathode is not large enough to generate a field enhancement factor as big as the Fowler-Nordheim equations require it to be for reasonable values to be produced.

In order to better understand this problem, it is of value to consider whether or not there are multiple sites field emitting, if the work function varies over the surface due to impurities or complications in the material, or if the surfaces worked with are actually rougher than they appear.

The question a proposed experiment would have to answer is, does field emission come from point spots, or does it come from local regions with low work functions? A successful experiment would permit beta and the work function to be distinguished from each other, and would likely indicate the work function as the source of the problem. Taking this idea further, how impurities affect work function could be investigated. Data taken from such an experiment would be fitted using (1), and two different sets of work function and beta values could be used. If both sets were not able to give an acceptable fit, beta and work function would be distinguishable from one another. While this experiment has not yet been proposed, it is possible to carry it out, and doing so would be of value.

CURRENT STATUS

The photoemission gun will now undergo initial testing to determine if the components will experience breakdown. This will take place step-by-step, first testing the insulators, then adding the stalk, and then finally the electrodes. If testing is successful, the mark II photoemission gun will be relocated to the current injector site, replacing the mark I.

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