Superconducting RF Photocathode Gun for Low Emittance Polarized Electron Beams*

D. Holmes#, H. Bluem, B. Abel, A. Favale, E. Peterson, J. Rathke, T. Schultheiss, A. Todd
Advanced Energy Systems, Inc., Medford NY USA
J. Kewisch, I. Ben-Zvi, A. Burrill, R. Grover, D. Pate, T. Rao, R. Todd
Brookhaven National Laboratory, Upton NY USA

Abstract

The use of an RF electron gun with a magnetized cathode in place of a DC gun for ILC may eliminate the need for emittance damping rings. So far only DC guns have been used to provide polarized electron beams because of the very high vacuum level needed for survival of the Gallium Arsenide (GaAs) cathode material used to generate polarized electrons. Maintaining adequate lifetime of GaAs cathode material requires vacuum levels in the 10^{-11} torr range. While vacuum levels around the 10^{-9} torr range are common in a normal conducting RF gun, the cryogenic pumping of the cavity walls of a superconducting RF (SRF) gun may maintain vacuum in the range needed for GaAs cathode longevity.

Advanced Energy Systems, Inc. is collaborating with Brookhaven National Laboratory to investigate the generation of polarized electron beams using a SRF photocathode gun. The team is developing an experiment to study the quantum lifetime of a GaAs cathode in a SRF cavity and investigate long term cavity performance while integrated with a cesiated GaAs cathode [1]. This paper reviews the design and analysis performed to develop a method to prepare and install GaAs cathodes into a SRF cavity in support of this experiment.

EXPERIMENT SETUP

At the heart of the experiment is a cesiated GaAs cathode installed in a ½ cell 1.3 GHz SRF cavity [2]. The cavity is coupled to a beam transport that includes a Non Evaporable Getter (NEG) vacuum pumping plenum followed by a solenoid focusing magnet and then a bending magnet that directs the beam into a faraday cup. A cathode clamping system is located on the back face of the cavity to secure the cathode in place. The SRF cavity is located inside a 100 liter cryostat for cool down prior to operation and is positioned vertically with the beam aperture facing upward allowing the beam to exit through the cryostat top cover. RF power input, pickup and instrumentation is fed into the system through the cryostat cover. The test setup arrangement and the 100 liter cryostat procured by BNL for this experiment is shown in figure 1.

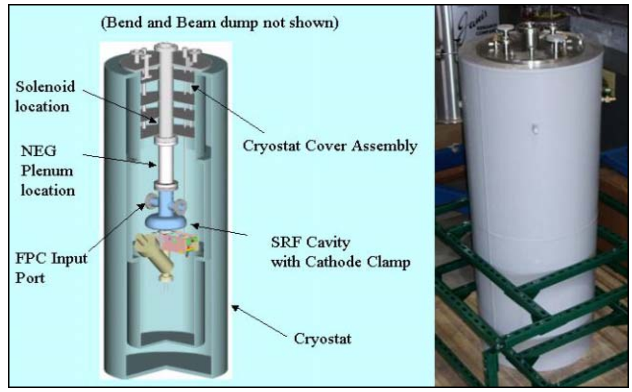

Figure 1. Test setup and cryostat

SYSTEM COMPONENTS

There are key subsystems required along with the main test setup to process and install the cathode in preparation of this experiment. The first is a process chamber to activate and cesiate the GaAs cathode material. The second is a transport assembly used to introduce the cathode into the process chamber and move it from the process chamber to the SRF gun cavity while under vacuum. The final piece is the SRF cavity hermetic string assembly itself that is integrated into the cryostat to run the experiment.

Process Chamber

The process chamber is a 10 inch diameter spherical vacuum vessel with an 8 inch vacuum port, an 8 inch viewport and ten smaller feedthru ports. One of the feedthru ports is used for the cathode insertion while other ports are utilized for a cesium source, oxygen bleed valve, cathode heater, cathode biasing, electron probe, and vacuum gauging. Windows on two of the ports are for a pyrometer to measure the cathode temperature during heating and a laser for in-situ QE measurement. A 270 liter/second ion pump with Titanium Sublimation Pumping (TSP) capability is coupled to the 8 inch vacuum port to maintain the required vacuum. The chamber exists at BNL where it was used on previous experimental QE and lifetime tests of Cesium-Potassium Antimonide cathode material. The chamber operated in the 10^{-11} torr vacuum range during these experiments. Figure 2 shows the chamber in this previous test setup while figure 3 illustrates how the chamber will be reconfigured for GaAs cathode processing.

* Work supported by The Department of Energy under SBIR Application No. 80384S06-II grant
#doug_holmes@mail.aesys.net

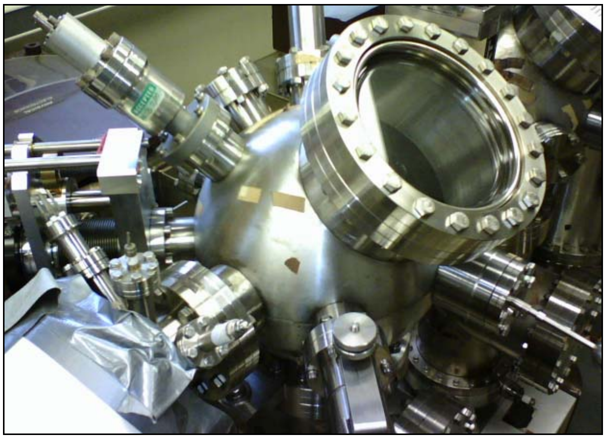

Figure 2. Cathode process chamber

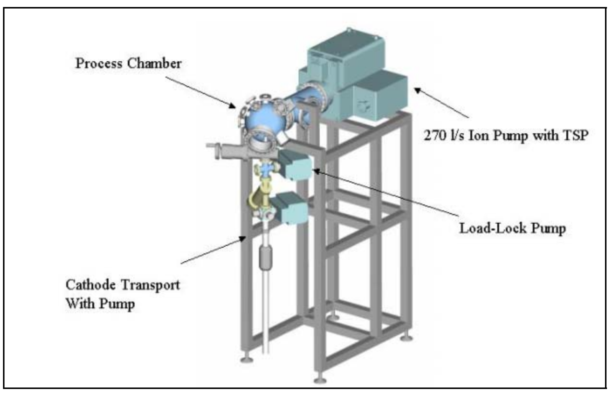

Figure 3. Process chamber arrangement

Cathode Transport

A transport assembly is planned for initial cathode pump down and then for cathode insertion through a load lock arrangement into either the process chamber or the SRF cavity. The transporter uses a magnetically coupled actuator to extend the cathode through the load lock valves. A ¼-turn bayonet style attachment mechanism is integrated into the end of the actuator. This arrangement enables detachment and retraction of the actuator from the cathode after placement into either the process chamber or SRF cavity. Once the actuator is retracted, the transporter can then be removed from the SRF cavity string in preparation for cavity testing. Figure 4 illustrates the ¼- turn bayonet attachment arrangement.

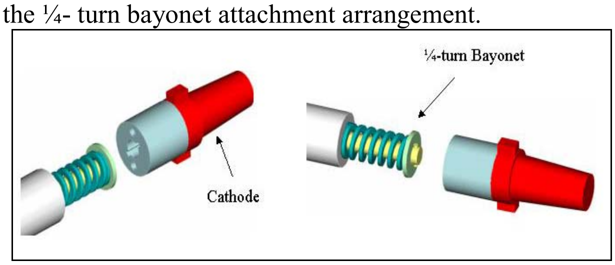

Figure 4. Attachment mechanism

The transport assembly includes a 6-way cross for mounting a vacuum ion pump along with a viewports and vacuum gauging. The arrangement of the transport assembly is shown in figure 5.

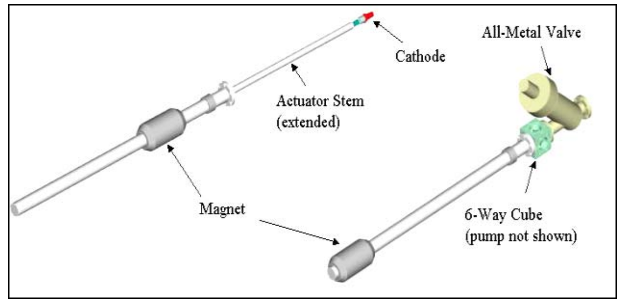

Figure 5. Transport assembly

SRF Cavity Assembly

Design modifications of an existing 1.3 GHz SRF cavity are developed to incorporate a socket to its back face for cathode insertion. The unmodified cavity is shown in figure 6.

Figure 6. 1.3 GHz gun cavity

The socket design features enable insertion and positioning a plug-style cathode with a RF face seal. A conflat flange is incorporated for vacuum sealing. The design is illustrated in figure 7.

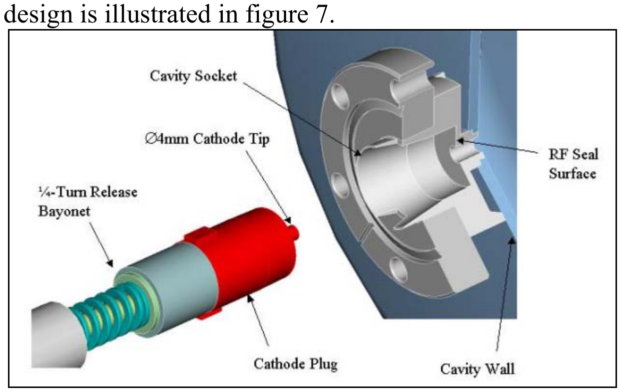

Figure 7. Cathode socket arrangement

A clamp system is used to secure the cathode into the SRF cavity socket during operation. The clamp system arrangement is capable of securing the cathode into the gun cavity while maintaining beam line cleanliness required for SRF operation. Figure 8 shows the clamp system installed on the gun cavity.

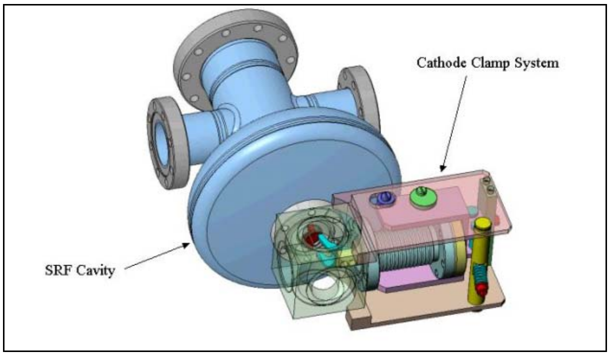

Figure 8. Cathode clamp system

Mounting provisions are incorporated in the clamp to attach a load lock arrangement for cathode insertion using the cathode transport assembly. The buildup sequence for cathode insertion into the gun cavity hermetic string is illustrated in figure 9.

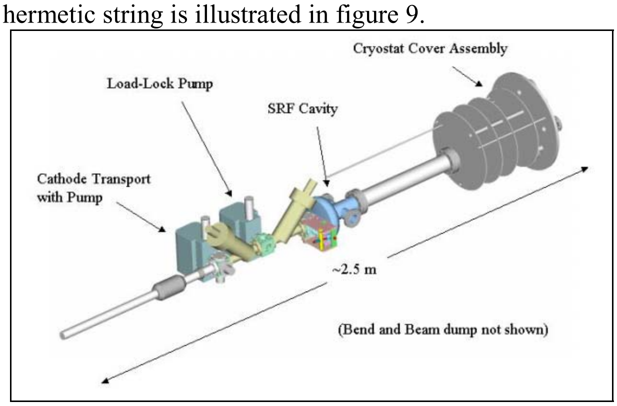

Figure 9. Cathode Insertion

Engineering Analysis

A thermal Finite Elemenet Analysis (FEA) using ANSYS was performed to evaluate the temperate of the SRF cavity during operation. This analysis considered the thermal load to the cavity resulting from dielectric losses of the GaAs material as well as RF losses in the superconducting niobium material. The thermal load was evaluated for three different GaAs material sizes based on a dielectric constant of 12.88 and a loss tangent of .0004. The electric field at the cathode was assumed to be 20 MV/m. Table 1 lists the calculated thermal load from the GaAs dielectric material for each size considered.

Table 1: GaAs Heat Loads

GaAs Material Size	**Dielectric Loss (watts)**
1 mm diameter X 50 µm thick	2.93
3 mm diameter X 10 µm thick	5.27
3 mm diameter X 50 µm thick	26.3

The FEA model included the cathode half of the SRF cavity and the cathode socket geometry. Thermal contact resistance between the cathode and the cavity was modeled assuming 10 psi pressure across the RF seal surface. The analysis included temperature dependent RF losses on the superconducting surface and thermal conductivity of the niobium material. FEA modeled components are show in figure 10.

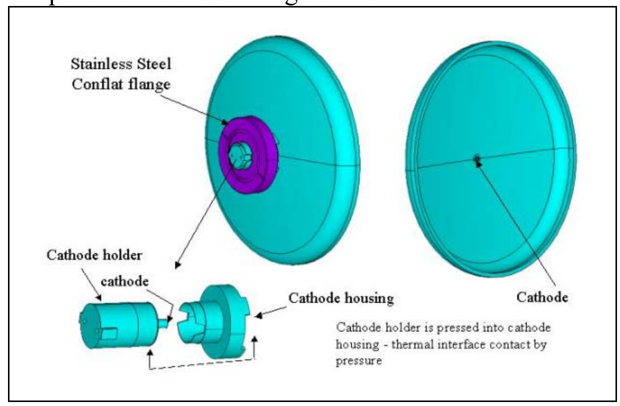

Figure 10. FEA model of SRF gun, cathode half

The boundary conditions of the analysis included the superfluid helium on the cavity outer surface at 2.0 K and Kapitza resistance at the fluid-to-surface interface. Figure 11 illustrates the surfaces of this boundary condition and the RF heat load applied to the cavity.

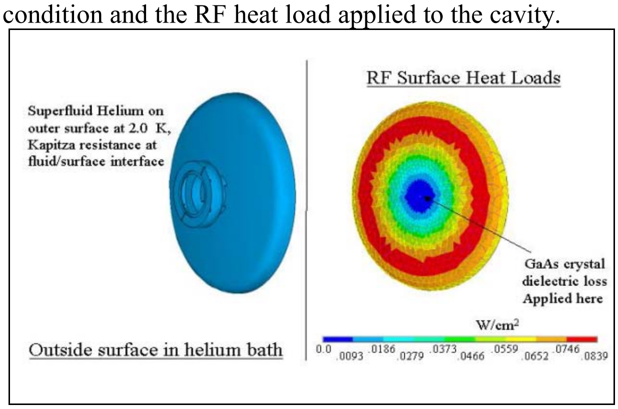

Figure 11. Boundary conditions and RF heat load

Analysis results of continuous RF heat loading and dielectric losses indicate cavity wall temperatures will remain below the critical temperature of the superconducting niobium for both the 1 mm diameter x 50 µm thick and the 3 mm diameter x 10 µm thick GaAs material sizes. The niobium cathode surface in contact with the GaAs does become normal conducting, however, surface currents are low enough not to cause the cavity to quench. Analysis indicates heat loads from CW RF operation of the cavity with the 3 mm diameter x 50 µm thick GaAs material does result in a cavity quench. Figure 12 depicts the cavity temperature profile indicated by the analysis of CW cavity operation with the 1 mm diameter x 50 µm thick GaAs material.

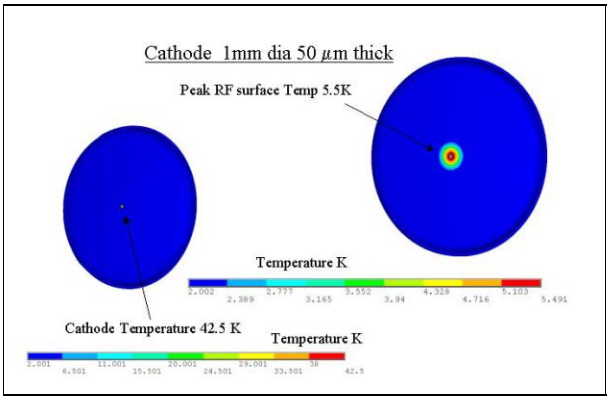

Figure 12. Analysis results

This analysis highlights the importance of minimizing the GaAs material volume to limit dielectric losses and the need to develop a process yielding thin GaAs attached to niobium suitable for use in a SRF environment.

STATUS AND SCHEDULE

BNL has received the cryostat for this experiment and has leak checked the assembly. The existing unmodified 1.3 GHz SRF gun cavity has been processed and has successfully undergone initial high power tests. BNL is preparing to retest the unmodified cavity in the cryostat procured for this experiment to establish baseline operation data. These initial baseline tests are scheduled for Late 2007

Significant design and analysis to develop a system to prepare GaAs cathodes for installation into a SRF cavity is completed and these activities are scheduled to continue through summer 2008. Assembly of the process chamber system is scheduled to be complete in Spring 2008 while the experimental setup will be manufactured by Fall 2008.

REFRENCES

[1] Jőrg Kewisch et al., The Polarized SRF Gun Experiment, Proceedings of the XIIth International Workshop on Polarized Sources, Targets & Polarimetry, Brookhaven National Laboratory, Upton NY, September 10-14, 2007

[2] M. Cole et al., RF design and Operating Performance of the BNL/AES 1.3 GHz Single Cell Superconducting RF Photocathode Electron Gun, Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee