AN INVERTED CERAMIC DC ELECTRON GUN FOR THE JEFFERSON LABORATORY FEL

S.V. Benson, G. Biallas, D. Bullard, F. Ellingsworth, P. Evtushenko, F.E. Hannon*, C. Hernandez-Garcia, K. Jordan, M. Marchlik, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

Abstract

A new 500kV DC photocathode electron gun is being developed at Jefferson Laboratory (JLab) with the aim of improving on the performance of the present FEL injector. The design benefits from the use of two inverted ceramic insulators to allow for a photocathode preparation chamber and load-lock system to be placed directly behind the gun. The electrostatic design emphasises the requirement to minimise the electric field gradients on the internal surfaces and incorporates shaped electrodes to provide some transverse focusing to the electron beam. Finally, provisions have been made to maintain ultra high vacuum conditions inside the gun chamber to prolong cathode lifetime during CW operation. This paper presents an overview of the electron gun and load-lock design.

INTRODUCTION

JLab aim to improve the reliability and quality of the electron beam delivered to the FEL. Down-time related to gun performance has been largely due to the difficulty in processing the high voltage electrodes and photocathode lifetime. The present design has maximum surface field gradients on the electrodes of approximately 8.7MV/m at the operational voltage of 350kV [1]. It has not always been possible to process out field emitters which result in gun trips from current surges, poor vacuum and therefore short cathode lifetime. To reduce these problems, the design philosophy was to reduce the gradients inside the gun to below 10MV/m at 500kV, improve the vacuum during operation with increased pumping speed, and introduce a load-lock system for quick cathode replacement when the quantum efficiency is low.

The mechanical design for the JLab-FEL gun is based on a similar inverted ceramic gun that was developed by the polarized source group at CEBAF-JLab. The CEBAF gun is designed to operate at 200kV and is undergoing electrostatic testing. The insulator and a test electrode have been biased to 215kV without damage. The onset of field emission was found at ~150kV for 10MV/m fields on an electrode made of single-crystal niobium [2].

GUN DESIGN

An overview of the electron gun design can be seen in figure 1. The gun is designed to nominally deliver 135pC electron bunches at a repetition rate of 75MHz and operate at a voltage of 500kV.

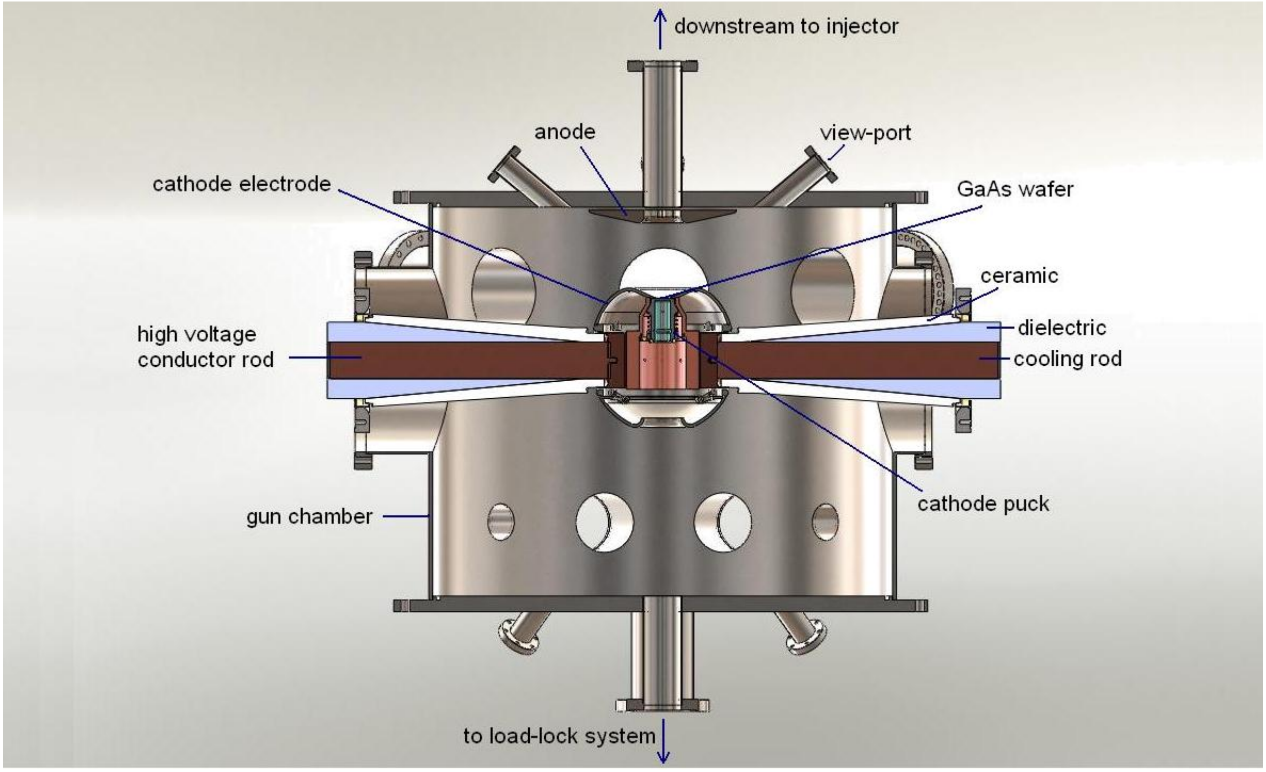

Figure 1: Cross-section overview of the inverted ceramic gun from above

---

*fhannon@jlab.org

The size of the electron gun vacuum chamber is determined by the ceramic geometry required to hold off the 500kV. The gun chamber is therefore 30” in diameter to accommodate the two ceramic structures.

Located behind the gun chamber is the load-lock and cathode preparation system. Internal to the vacuum chamber are the two conical ceramics, which support the cathode electrode in the center. The cathode and anode electrodes are shaped to provide transverse focusing to the electron bunches emitted from the cathode in the low energy region.

Load-lock and Cathode Preparation Chamber

The load-lock system is situated directly behind the gun tank and is separated by a gate valve to prevent contamination of the gun chamber when cathodes are being prepared, see figure 2.

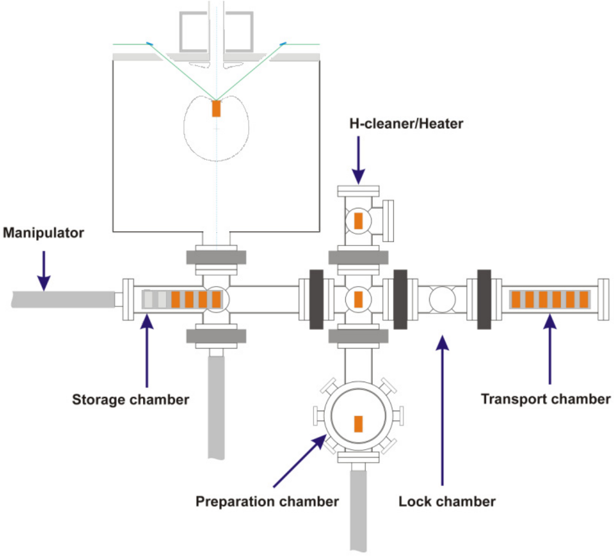

Figure 2: Schematic of the load-lock and cathode preparation system

The load-lock can house up to 6 cathode pucks that are mounted onto a removable cassette. Each cathode can be selected from the magazine for insertion into the gun chamber using a manipulator arm inside long bellows. Initially it is expected that GaAs cathodes will be used as JLab already have the appropriate procedures for producing high quantum efficiency, and also have a matched laser system. For this reason, a cathode preparation system for heat cleaning the GaAs wafers and depositing Cs and NF_3 onto the surface is also located behind the gun. The preparation system can be isolated from the insertion mechanism so that the gun vacuum is preserved. This design does not preclude the use of other cathodes in the future that may require different preparation formulas, as it can be modified to include additional chambers.

Cathode and Puck Design

Each cathode is 1.2 inches in diameter and is attached to a puck with indium foil and a crimped soft tantalum cup. The design of the puck is shown in figure 3. The conical region at the front of the puck has been shaped such that the cathode face is perpendicular to the cathode ball electrode. Good thermal contact is required between these faces as the cathode will be cooled through this interface. For this reason, each puck will be precisely machined to match the internal contours inside the electrode ball. The notch is to ensure that the orientation of every cathode is the same each time it is inserted into the gun. The puck itself is held inside the cathode ball with a spring mechanism that pushes the cathode wafer towards the front electrode surface.

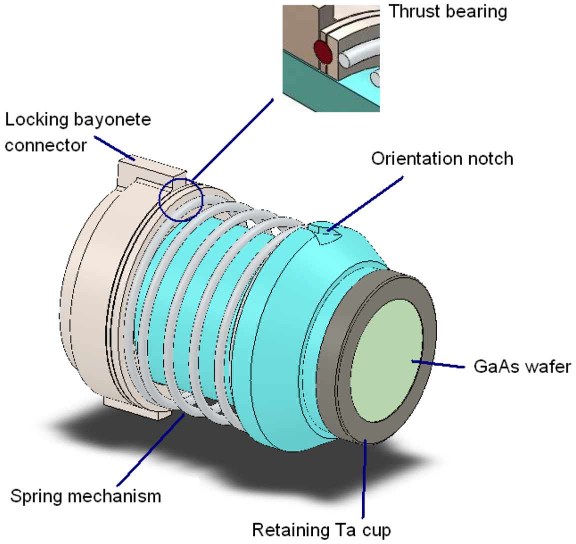

Figure 3: Cathode puck mechanism

Vacuum requirements

The vacuum in the present FEL electron gun can be measured at $3x10^{-11}$ Torr [3]. The vacuum chamber volume of the inverted gun is three times larger than the FEL gun, and so requires more vacuum pumping capability. To this end, three NEG pumps are positioned at the front of the chamber, directly below the cathode anode gap. They each have a pumping speed of 1000l/s. At the rear of the vacuum chamber, there are two flanges with 40l/s ion pumps attached and two further flanges for the addition of two 1000l/s NEG pumps.

For the purposes of the initial pump down of the chamber and during bake-out a 100l/s ion pump will be used. It will be backed with a 300l/s turbo pump that should specifically aid in the removal of noble gases during bake out. It is attached by a 6” flange to ensure good conductance and hence rapid pump-down times.

Finally, there is an instrument port available on top of the chamber for additional vacuum equipment. An extractor gauge will be used for measuring the vacuum in the 10^{-12} Torr range. A residual gas analysis diagnostics will be used to monitor molecular species in the tank and measure higher pressures. Additionally, a leak valve has been included to allow for the possibility of krypton processing. Introducing krypton into the tank during high voltage processing of the electrodes in the FEL gun has proved useful in suppressing some field emitters [4].

Electrostatic Design

The complete electrostatic structure consists of the two ceramics, the cathode and anode electrodes. The ceramics are approximately 39cm long and have a bulk resistivity of 1×10^{11} Ωm, chosen to drain charge build up from field emission. Inside one ceramic is a conductive rod surrounded by the dielectric material fluorinated ethylene propylene. The conductive rod is connected to the high voltage power supply. The dielectric material is required to reduce the possibility of electrical breakdown between the conductive rod and the ceramic. Fluorinated ethylene propylene has a breakdown gradient of approximately 70 MV/m and the maximum gradient expected at the dielectric/conductive rod interface has been modelled around 20MV/m.

The ceramics hold the cathode ball in the centre of the gun chamber tank. The cathode ball is composed of four niobium shells clamped around the cathode holder assembly inside. It is envisaged that two sets of cathode electrodes will be manufactured, one out of large grain niobium and another from fine grain material. From experience at JLab in producing SRF cavities from these materials it is hoped that the large grain material will only have to undergo buffered chemical polishing in order to produce a smooth enough surface to minimise field emission. The fine grain electrodes will also require electro-polishing to produce the required surface finish. The diameter of the ball is 24cm, chosen to limit the surface electric field to below 10MV/m. This requirement is what defined the radius of the cylindrical gun chamber.

The shape of the cathode and anode electrodes was a result of three design constraints; keeping the surface fields below 10MV/m, providing some transverse focusing to the electron beam, and maintaining good electron beam properties for various operation scenarios. Figure 4 shows the cathode electrode shape.

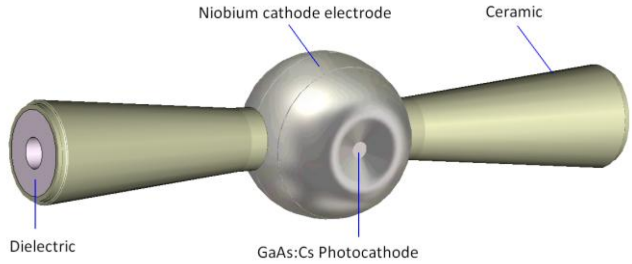

Figure 4: Cathode electrode and ceramic geometry.

The maximum gradient in the gun is on the cathode surface at the curved interface to the focusing geometry. Simulations estimate this to be 8.5MV/m, shown in figure 5. Note that this gradient at 500kV is only slightly larger than that in the FEL gun at 350kV. The anode plate will be electrically insulated from the gun chamber. With this feature a bias of a few kV can be applied to the anode. This serves two purposes; first, applying a positive bias to the anode can prevent any ions that are accumulated in the beam downstream of the gun penetrating back into the chamber. This is particularly important when running CW beam, and should reduce the ion back bombardment current to the cathode, which in turn improves the cathode lifetime. Second, the current from field emitted electrons that travel from the cathode to anode can be measured with an insulated anode.

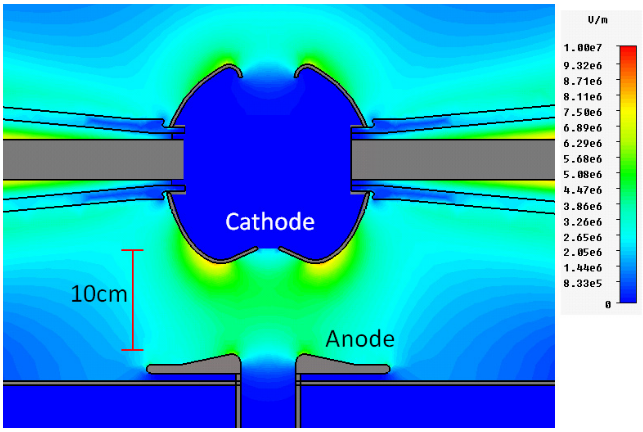

Figure 5: View from above of the absolute electric field gradient for the electron gun at 500kV.

FUTURE OUTLOOK

The gun is scheduled for completion in November 2009. Once the gun is fully assembled in a clean room it will then be placed in the Gun Test Facility. Here it will undergo a long first bake followed by high voltage processing and ultimately beam testing. A diagnostic beamline will be used to verify simulations of electron beam properties.

Later in 2010 it is expected that a new injector beamline will be installed in the FEL. At this time the gun and load-lock system will be moved into the FEL to be used in combination with an upgraded booster module.

ACKNOWLEDGMENTS

This work is supported by the Office of Naval Research, the Joint Technology Office, the Air Force Research Laboratory, U.S. Night Vision Lab, the Commonwealth of Virginia, and by DOE Contract DE-AC05-060R23177. The authors wish to thank Jochen Teichert, Boris Militsyn and Matt Poelker for their help and advice on this project.

REFERECES

[1] T. Siggins, et al., Nuclear Instruments and Methods, Sect. A **475**, 549 (2001)
[2] M. Poelker et al., Proc. ERL Workshop 2009, in press
[3] C. Hernandez-Garcia, et al., Proc. PAC 2005
[4] C. Hernandez-Garcia, et al., Proc. SPIN-PESP 2008