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THE PROGRESS OF HIGH CURRENT HIGH BUNCH CHARGE POLARIZED ELECTRON HVDC GUN*

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Abstract

High bunch charge (nC level), high average current (mA level), with above kC charge lifetime, is yet to be demonstrated and has been one of the main focus of research in the field of polarized electron sources. Improving the charge lifetime from a polarized electron source will be beneficial towards various project such as LHeC, positron source as well as polarized electron microscope. Our gun aims to deliver polarized electron beam with 10 mA average current and 5.3 nC bunch charge. We analyzed the mechanism of cathode degradation and proposed using a large strain superlattice GaAs photocathode in a high voltage DC gun to increase the charge lifetime above kilo Coulomb. An anode off-centered with transverse magnetic kick scheme are proposed to increase the charge lifeitime. The gun has been designed, fabricated and expected to start commissioning by the end of this year. In this paper, we will present the modeling of ion back bombardment and cathode degrading. Also, we will describe the details of gun design and the strategies to demonstrate high current high charge polarized electron beam from this source.

INTRODUCTION

Polarized electron sources have been used in particle and nuclear physics experiments around the world. Improving the charge lifetime from a polarized electron source will be beneficial towards various electron ion collider projects such as LHeC and CBeta-EIC. It also has recently been shown that a high intensity polarized electron source can be used to produce high intensity polarized positron beams with many possible applications in the future.[1]

The most efficient way to generate short pulse polarized electron bunches is using Super Lattice GaAs (SL-GaAs) in a high voltage DC gun. The SL-GaAs photocathodes can provide electron beams with a polarization of up to 92 %, with QE of 1% approximately at IR laser illumination. To preserve the polarization and obtain high QE, the photocathodes are prepared to have Negative Electron Affinity (NEA) on the surface by coating with a monolayer formed by alkali metal oxidant (O_2 or NF_3). This NEA layer is extremely sensitive to the residual gas and ions back bombardment during operation, causing relatively short cathode lifetime. The best charge lifetime from a SL-GaAs cathode is no more than 400 Coulomb. Such cathodes should be operated below 10^{-11} torr vacuum with partial pressure of water less than 10^{-13} torr. The GaAs coating with robust layer is in investigating as well.

Besides the cathode and vacuum R&D, multiple operational techniques have been implemented to improve the lifetime of GaAs photocathodes in DC guns. For example, i) Radially offsetting the laser spot from the cathode center to avoid high energy ion back bombardment; ii) Limiting the cathode active area to reduce transverse beam halo; iii) Biasing the anode or using ion cleaning electrodes to remove back bombarded ions originating from downstream beamlines; iv) Increasing the laser spot size; v) Off-centered anode [3].

We are developing a large cathode HVDC gun based on inverted high voltage feed through. Multiple new features including are integrated into the gun design to expect generating kC charge lifetime time. This proceeding will discuss the analysis of the cathode charge lifetime as well we the new features we developed.

ION BACK BOMBARDMENT ESTIMATION

The ion back bombardment dominated photocathode decay can be described by a differential equation as following.

$$\frac{E(t)}{B}\, F\, I\, d\, t = -d\, E(t) \qquad (1)$$

where E(t) is the emission area that is capable to emit electrons at time t. B is the initial emission area. Idt is the charge emits in duration of dt and F is ions generated by 1C electrons. F can be expressed as,

$$F(ni, \sigma(E)) = \frac{ni}{e}\int_0^d \sigma\left(\int_0^Z E_{field}(z)dz\right)dz \qquad (2)$$

Where ni is density of residual gas molecule, d is the distance that ions can trace back to the cathode, σ is the ionization cross section of electron-hydrogen molecules and E_{field} is the field gradient along the gun axis. Here, we are assuming the laser spot is on the centre of the cathode. For the laser off-center case, the ion back bombardment can be estimated by the 3D ion tracking-simulation package which developed by the authors.[4]

When the beam current is constant, solving the Eqn 1, the QE decay after duration τ is

$$E_{end}(\tau) = B\, e^{-\frac{I}{B}F\,\tau} \qquad (3)$$

resulting the cathode charge lifetime to be

$$Charge\ lifetime = \frac{B}{F}\, Log\left(\frac{B}{E_{end}}\right) \qquad (4)$$

The cathode lifetime usually is defined by the QE drop to 1/e, thus the log(B/E_{end}) is 1. The charge lifetime is B/F which proportional to the cathode size and inverse propor-

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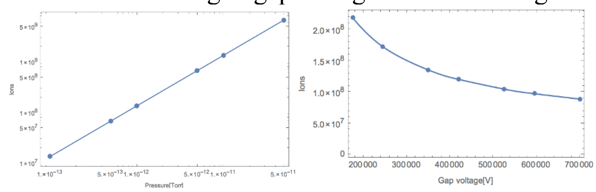
tional to the F (The number of ions generated by 1C electrons), inverse proportional to the pressure, increase by enhance the voltage as shown in Fig. 1a.

Without beam loss, the ions generated by the electrons are constant. The ions generated as the function of vacuum pressure and the DC gun gap voltage is shown in Fig.1b.



(a) (b)

Figure 1: a) and b) are the generated ions number as the function of pressure and DC gap voltage, respectly.

For high charge and high current beam, the beam loss has to be considered. With constant peak current, the beam loss is proportional to average current, causing the charge lifetime decreasing once the average current goes up, as shown in Fig. 2.

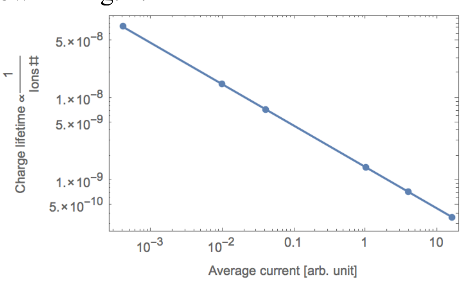


Figure 2: With the beam loss, the cathode charge lifetime as the function of average current.

HV DC GUN DESIGN

Most of the challenges in meeting the high current polarized beam requirements are related to the photocathode properties, its sensitivity and associated lifetime. The ion back bombardment will be enhanced with bad vacuum and beam loss. Cathode heating up by the high-power laser is another source to degrade the QE at high current operation.[2]

The last section shows that the cathode charge lifetime is a linear function with emission area. Increasing the cathode size and properly design the high charge beam optics will enhance the cathode charge lifetime. Off-centered laser spot is already demonstrated to enhance the lifetime. Considering both ion back bombardment effect (2mm offset) , edge effect (4 mm to the edge) and 6mm diameter of the cathode's illuminated spot, we need a cathode with a diameter above 24 mm to match the current density/charge density achieved in state of the art measurements. Following above discussion, a high current/ high charge long operation polarized electron gun needs following features: i) Hydrogen dominated XHV gun chamber; ii) Large aperture beamline; iii) Heavy surface doped superlattice GaAs/GaAsP photocathode; iv) Active cooling capability or heat sink; v) Large photocathode; vi) High voltage. In order to reduce the risk of time consuming high voltage study, we are working on developing a single cathode inverted high voltage DC gun whose geometry concept is based on JLab inverted gun, but has several improvement. The HV and vacuum components are all commercial parts. The improvements are including:

- The cathode size is enlarged by a factor of four;
- Add large copper block at back of cathode as heat sink. New designed high voltage feedthrough intergraded with cooling return loop which can hold up to 10 W.
- 3D Moveable anode assembly.
- Two pieces electrode ball assembly.
- Increase beam pipe diameter up to 10 cm.
- Transversely kick the beam in DC gap and the beam pass through the off-centred anode that will shift ions away from the cathode.

Table 1: The Gun Parameters

	Inverted gun
Electrodes diameter	20 cm
Gap distance (lg)	5.7 cm
Voltage	350 kV
Cathode size	4.98 cm^2
Electrodes angle (α)	22 degs
Cathode gradients	3.8 MV/m
Maximum gradient	9.8 MV/m
Anode radius (la)	1.8 cm
Pumping speed	35000 L/s

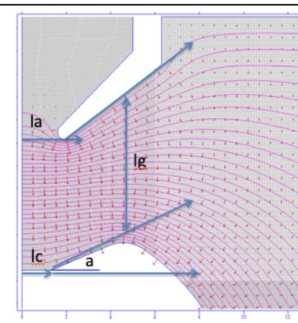


Figure 3: The DC gun geometry.

Figure 3 shows the Possion statics electrical field simulation. Four parameters are optimized including gap distance(lg), Pierce angle(a), cathode size(lc) and anode aperture(la). The anode cone angle is same as the Perice-like angle. The gun geometry is optimized by minimum the emittance and keeping the beam away from the anode aperture as shown in Figure 4. The anode defocusing length is -22 cm while the space charge defocusing can be calculated by eqn. 5

$$\frac{1}{f_{sc}} = -\frac{I_{peak}\ gap\ mc^2}{I_0 r^2 eV}\frac{1}{\beta_f \gamma_f} ln\frac{(1+\gamma_i)gap}{(1+\gamma_f)z_i} \quad (5)$$

With 1.5ns and 6nC charge, the space charge defocusing length is -9.7cm. The laser size is 4mm in radius with 6mm off-centered. The optimized DC gap geometry parameters are presented in Table 1. The anode is designed to be 3D movable. It could be used for optimizing the optics in gun operation. With this feature, we proposed to extract the beam from off-centered anode, resulting in shift the ions away from the cathode and extend the charge lifetime by at

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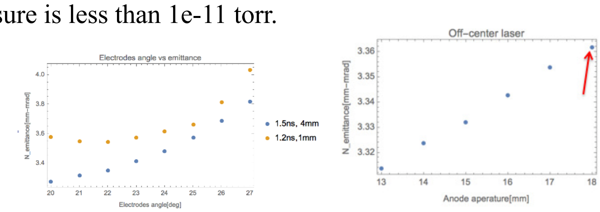
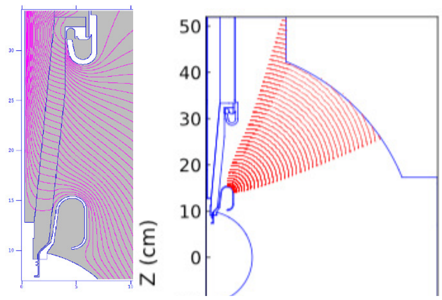
least factor of 5. The emittance increasing due to the transverse kick is minimal. The detailed new scheme simulation and discussion are presented in ref [3].

With this design, the expected average current is 10 mA with 1000 C charge lifetime if the dynamic vacuum pressure is less than 1e-11 torr.



(a) (b)

Figure 4 : a)The pierce angle as the function of normalized emittance. b) the anode aperture as the function of normalized emittance.



(a) (b)

Figure 5: The DC field simulation at high voltage feedthrough with two triple-point sheds which provide linear field distribution on the ceramic and reduced the field on the triple-point. The field emission code shows the electron may emit out if the emission threshed is 9 MV/m

Learning experiences from the JLab inverted gun operation, we designed new trible point shed to protect two ceramic-metal-air joints from arcing as shown on Fig.5. The new shed has advantages such as thin wall and less transvers kick. The field gradient on the shed is reduced by 10 %. The maximum gradient on the top curve is 9 MV/m.

VACUUM AND BEAMLINE DESIGN

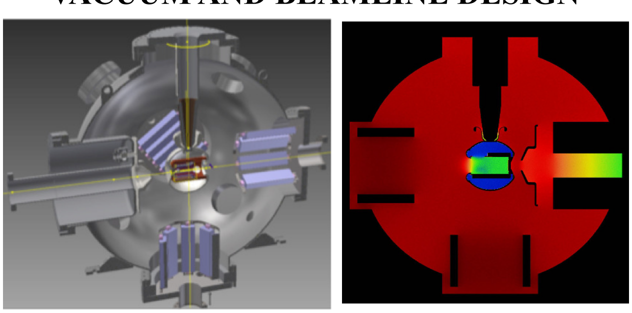


Figure 6: The DC gun geometry and vacuum simulation using Mol-flow.

All the gun components have been 900 °C fired, then a 450 °C vacuum oven baked. There are 30000 L/s NEGs are installed into the gun vessel. The re-entry beamline at the side of anode is NEG coated. Our Molflow simulation shows the cathode pressure can achieve 1x10^{-12} torr if the SS outgassing rate can reach the design value. A 3BG gauge will be used for measuring the XHV. The beamline is made by Ti with the 4000 L/s TSP pump with two ion pumps. The expected pressure will be low-10^{-11} torr when the Faraday cup has 10^{-9} torr outgassing.

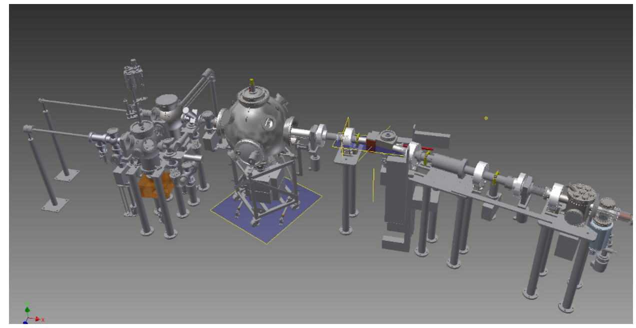


Figure 7: The beamline schematic drawing of the polarized gun.

Figure 7 shows the beamline for testing the high charge(up to 12 nC) and high average current (up to 10 mA). There is a 16° dipole magnet to reduce the ions from the Faraday cup. The beamline has been simulated by GPT code. Five solenoids maintain the beam envelop down to 30% of the beamline size. Before the Faraday cup, there is a 3 mm aperture at the diagnostic chamber to provide a differential pumping. It has been achieved 5x10^{-12} torr after two weeks bake. The initial beam size is 8 mm in diameter and the bunch charge is 6 nC. Figure 8 shows the RMS beam size from the cathode to Faraday cup.

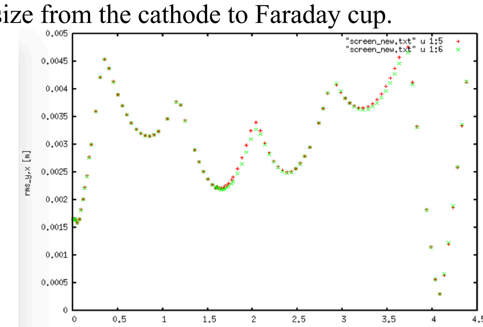


Figure 8: The rms beam size.

For the dual applications, this gun will be used for testing high charge up to 12 nC with low repetition frequency for eRHIC. The bunch length will be increased to maintain the similar current density.

The gun is in final assembly stage and is expected to be ready for beam commissioning by the end of this year.

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