High Voltage Insulators for 500 kV DC High Voltage Photogun with Inverted Insulator Design

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Soon after the first demonstration of spin polarized electron beams from GaAs, DC high voltage photoguns were built to conduct nuclear physics experiments at SLAC, MIT-Bates, the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (JLab), Bonn-ELSA, Mainz University MAMI, NIKHEV and Nagoya University – all of these photoguns operated at approximately 100 kV bias voltage. Today, only the photoguns at Mainz and CEBAF still regularly produce spin-polarized beams at 100 and 130 keV, respectively [1,2]. These voltages are sufficient to satisfy the electron beam requirements of the accelerators they serve.

More recently, interest in light sources, with stringent emittance requirements, spurred R&D devoted to operating DC high voltage photoguns at much high voltages. The photogun used to drive the JLab Free Electron Laser (FEL) provided milliampere beams at 350 keV [3] using a concentric cathode electrode support, with the biggest drawback of this gun design being the absence of a load lock for photocathode activation and replacement. KEK and Cornell University added load-locked vacuum chambers using a side-insulator design [4,5], and they solved the very challenging problem of high voltage breakdown that sometimes results in insulator punch-through, by using segmented insulator rings with interior metal shields. With their designs, there is no line-of-sight for field emitted electrons to reach the surface of the insulator where they can cause severe damage.

Highlights of the achievements demonstrated using the KEK and Cornell University DC high voltage photogun designs include 2 mA CW beam delivery at 500 kV bias voltage [6], record level average current of 65 mA CW with photogun biased at 250 kV [7], and most recently sustained ~ 30 mA CW beam delivery at 400 kV bias voltage to demonstrate bunched beam cooling at RHIC [8]. Without intending to diminish these remarkable achievements, all of these photoguns including the JLab FEL 350 kV vent/bake photogun, exhibit small levels of field emission that would be problematic for polarized beam production.

At Jefferson Lab, we have chosen an “inverted-insulator” high voltage design, where the insulator extends into the vacuum chamber from the top serving as the cathode electrode support structure. With the inverted insulator perpendicular to the beam line axis, the photocathode load-lock chamber naturally attaches to the back end of the photogun, just like the photoguns with large cylindrical insulators. But high voltage is applied to the cathode electrode using a commercial high voltage cable that connects to a power supply, providing some flexibility in terms of positioning the required SF_6 tank. Because the insulator serves as the electrode support structure, the photogun design is compact, which can result in improved vacuum compared to other designs, and it is small enough to fit in places where there are tight vertical space constraints. And finally, there is comparatively small metallic surface biased at high voltage, which serves to minimize the possibility of field emission.

The 130 kV spin-polarized inverted-insulator photogun at CEBAF [2] shown in figure 1 is very compact, provides exceptional vacuum (low 10^{-12} Torr) and exhibits NO field emission. These properties provide a charge lifetime in the range of 200 to 400 Coulombs, which is sufficient to satisfy the beam delivery requirements of the CEBAF nuclear physics program using only one photocathode activation, from start to finish of the run (the laser is moved to fresh photocathode quantum efficiency locations during the run).

A larger version of this photogun design operates at 300 kV bias voltage and successfully makes tens of milliamperes of unpolarized beam using alkali-antimonide photocathodes [9]. To operate at 300 kV, the photogun was processed to 360 kV, but even with 60 kV of high voltage "headroom", it was insufficient to COMPLETELY eliminate field emission – there is still nanoampere levels of field emission current which poses no problem for making unpolarized magnetized beams with alkali-antimonide photocathodes, however this would be problematic for a GaAs photocathode illuminated with light near the band-gap necessary for generating polarized beam. Photocathode lifetime would be insufficient to maintain a User-based physics program and we are reluctant to apply higher voltage to "process out" the field emitters – experience suggests ~ 350 kV is the limit of the present inverted insulator size used in this design [10].

Positrons are in demand at Jefferson Lab, we would like to make polarized positron beams using the PEPPo technique [11], where the polarization of an electron drive beam is transferred to a positron beam via pair production within a conversion target. A 10 mA CW, 0.3 nC bunch charge, polarized electron beam drive for polarized positron beams motivates the need for an inverted insulator photogun operating reliably – without field emission – at 350 kV to manage space charge.

The purpose of this work is to demonstrate an inverted insulator + high voltage cable assembly that can be used to reliably apply 500 kV bias voltage to a test electrode, with no high voltage breakdown inside or outside the vacuum chamber, such that the developed system can be implemented in a future photogun capable of delivering spin polarized beam from GaAs photocathodes at 350 kV without measurable field emission.

This 350kV inverted insulator photogun design could then be used for generating a beam of spin-polarized electrons for the Electron Ion Collider at BNL, the International Linear Collider, the proposed SuperKEKB upgrade with polarized electron beams, as well as to drive a spin-polarized positron sources for high energy nuclear physics experiments like the Continuous Electron Beam Accelerator Facility at Jefferson Lab.

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