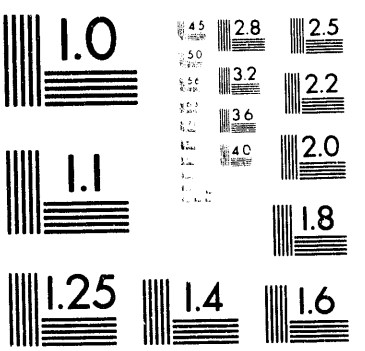
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SLAC-PUB-6193
April 1993
(A/I)

HIGH VOLTAGE PROCESSING OF THE SLC POLARIZED ELECTRON GUN*

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Abstract

The SLC polarized electron gun operates at 120 kV with very low dark current to maintain the ultra high vacuum (UHV). This strict requirement protects the extremely sensitive photocathode from contaminants caused by high voltage (HV) activity. Thorough HV processing is thus required. xray sensitive photographic film, a nanoammeter in series with the gun power supply, a radiation meter, a sensitive residual gas analyzer and surface xray spectrometry were used to study areas in the gun where HV activity occurred. By reducing the electric field gradients, carefully preparing the HV surfaces and adhering to very strict clean assembly procedures, we found it possible to process the gun so as to reduce both the dark current at operating voltage and the probability of HV discharge. These HV preparation and processing techniques are described.

I. INTRODUCTION

The polarized electron gun is essential for a new series of experiments at SLAC [1]. It uses a cesium activated GaAs photocathode to produce a longitudinally polarized electron beam which is injected into the accelerator. The activated photocathode is extremely sensitive to contamination and so must reside in an UHV environment (total pressure ~2×10^{-11} Torr). HV of 120 kV is required to produce a sufficiently high intensity electron beam and to properly inject the electrons into the accelerator. These conditions must coexist in a gun that will operate continuously for several months with minimal intervention.

The early SLC polarized guns (prior to 1992) had unacceptable HV problems. A single HV breakdown can reduce the QE [2] in the photocathode. Reactivation, as opposed to mere cesiation, is often required to restore the QE and is not always successful in doing so. High pressure levels associated with high dark current accelerate the drop in QE with time. We will first discuss how we diagnosed some of the HV problems and then describe the material preparation and HV processing techniques that have given us stable and reliable guns.

II. DIAGNOSTICS

One of the major sources of high voltage breakdown is field emission from metal surfaces. At very high electric fields (E ~ 3×10^9 V/m) the surface potential barrier for metals is small and thin enough for electrons to tunnel out, producing field emission [3]. Figure 1 shows the inside structure of the gun. EGUN [4] simulation of the gun electrodes gave a maximum electric field of 7×10^6 V/m on the cathode electrode [5] at 120 kV. Microscopic surface irregularities and/or contaminants can enhance this electric field in such a way to produce field emission [3].

A nanoammeter in series with the gun HV power supply was used to study the behavior of the gun dark current at high voltage. Figure 2 shows that these data are well represented by a Fowler-Nordheim form, where the slope of the curve indicates an electric field enhancement of $\beta \sim 500$ at the field emitting point.

The field emitted electrons are accelerated to the anode surfaces where they desorb gases and generate xrays. Figure 3 shows the spectrum of xrays emitted from the electrode region at 110 kV. The data approximate a Bremsstrahlung energy loss distribution. Xray sensitive photographic film [6] was used to map the xray emitting sites inside the gun. Xrays going through a small aperture on a lead plate fiducial, external to the gun, would cast an image on film arranged around the electrode area. Multiple small spots on the film indicated that the field emitting sources were discrete point sources. Ray tracing analysis showed that most field emitting points came from the cathode electrode and the cathode electrode support tube.

Surface samples taken from a gun after HV processing were viewed under a microscope and analyzed using a energy dispersive xray spectrometer (EDAX). Figure 4 shows the copper surface of the cathode electrode support tube in Gun #1. The highly polished copper surface has been disturbed, probably by ion bombardment during HV nitrogen processing (see below). Figure 5 shows a fragment of stainless steel on the polished cathode electrode, presumably the

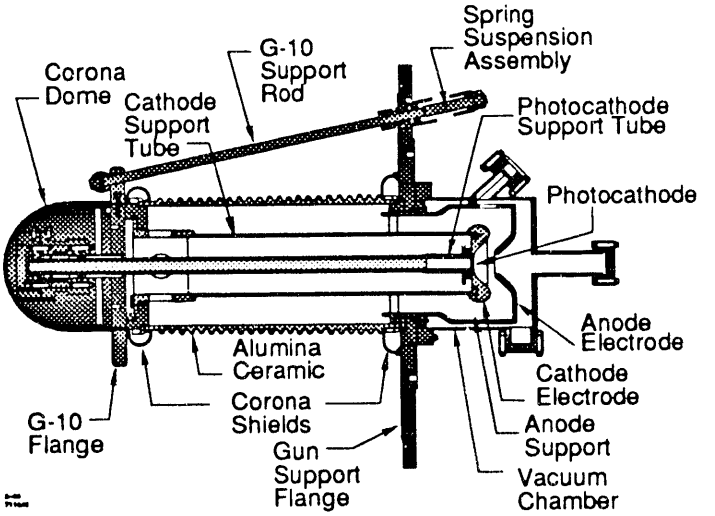

Figure 1. Schematic of the polarized electron gun.

* Work supported by Department of Energy contract DE-AC03-76SF00515.

Presented at the Particle Accelerator Conference (PAC 93), Washington, DC, May 17–20, 1993

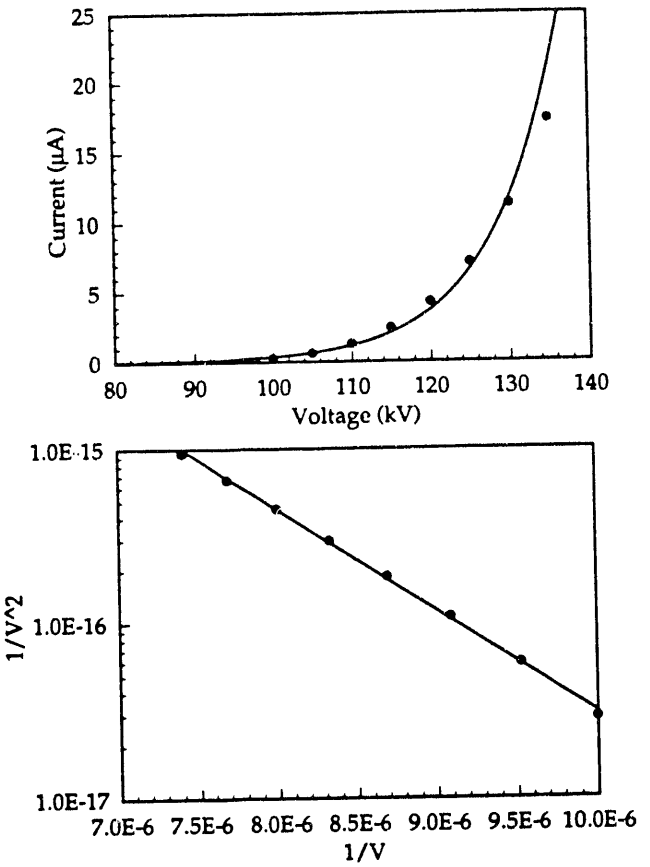

Figure 2. (a) Current versus voltage plot for Gun #3 (b) Fowler-Nordheim plot for Gun #3 with electric-field enhancement of $\beta \sim 500$.

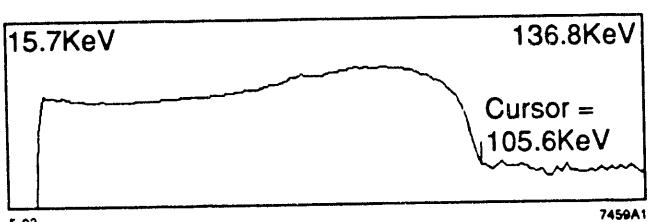

Figure 3. Energy distribution of emitted xrays for 110 kV.

Figure 4. Copper surface of cathode support tube.

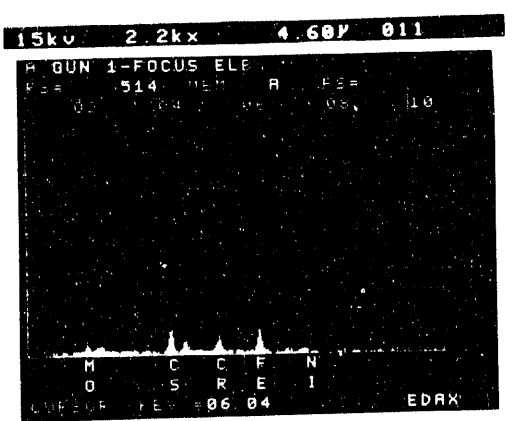

Figure 5. (a) Stainless steel fragment on polished cathode electrode and (b) EDAX plot of fragment contents.

fragment is a remnant from HV arcing. Figure 6 shows evidence of HV arcing activity on a polished electrode surface contaminated with potasium chloride. The potasium chloride contamination must have been introduced during the gun assembly.

Fowler-Nordheim plots and spectra of emitted xrays indicate that the HV activity comes from electron field emission. The EGUN simulation and xray film analysis point to the electrode area as the source of these electrons. The EDAX study shows that contamination during assembly can harm the HV performance.

III. MATERIAL PREPARATION

Selection and preparation of materials to be used for high field areas is critical. The material used in these areas is certified low carbon vacuum arc remelted stainless steel 304, 316, and on the electrodes 317. All tubing was seamless stainless steel 304L or 316L. Samples of these materials were metallographically evaluated for inclusion content and grain size. After the electrodes are machined using UHV procedures, they are chemically cleaned and hydrogen fired to 1050°C for 10 minutes. Then they are polished to a one micron finish. The material is cleaned again, inspected and

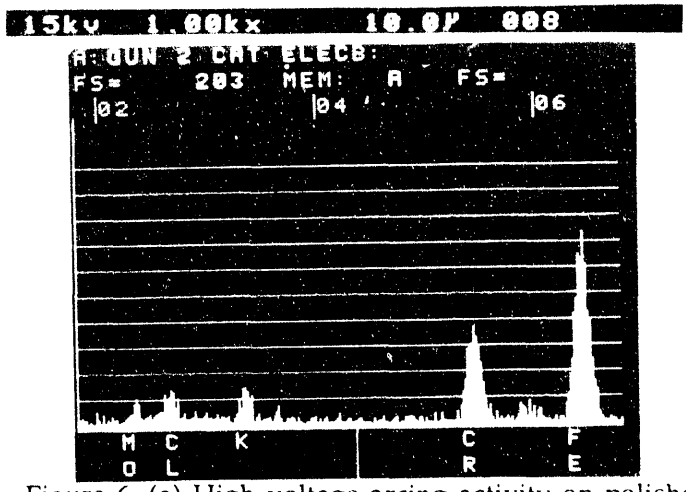

Figure 6. (a) High voltage arcing activity on polished electrode surface and (b) EDAX plot showing contamination with potassium chloride.

vacuum fired at 450°C until outgased. Finally we inspect the surfaces, and assemble all the components in a class 1000 clean room. Extreme cleanliness is emphasize throughout the process. Fixtures made of teflon are used for holding components during transport and extreme care is taken to prevent any contact with polished surfaces. The gun assembly is baked at 250°C for a minimum of 100 hours until outgased. The gun is then ready for high voltage processing.

IV. HIGH VOLTAGE PROCESSING

The gun HV processing is intentionally conservative; we minimize the amount of dark current (< 20 µA) to prevent permanent damage to the electrode structure. The main diagnostics used during processing are the nanoammeter in series with the HV power supply, a xray detector, and a Residual Gas Analyzer (RGA) which measures the partial pressures of gas species in the gun vacuum.

Our experience with HV processing of the guns has been as follows. The voltage is slowly raised to 60 kV with only minor discharge (spikes in the current together with small, short bursts of CO, H, and other gases). Above ~60 kV the guns start drawing 1-20 µA of current. Constant voltage is maintained until the current decreases, which may occur gradually or may occur suddenly after a HV discharge. To attain a dark current of less than 50 nA at the operating voltage of 120 kV, the guns are processed to 180 kV. The rate of raising the voltage varies, taking from a few hours to a few days. One technique that speeds the processing is to introduce dry nitrogen from liquid nitrogen boil-off into the gun to 10^{-6} Torr. When processing with nitrogen, 180 kV can be reached in a few hours [7].

Gun #3 showed unusually good behavior. It had very few arcs during the initial processing. After introducing and then pumping out some nitrogen without HV, the gun achieved 180 kV in just one hour with much less than 1 µA of dark current [8]. The other guns were more problematic and needed a few days of HV processing.

V. CONCLUSION

Good HV performance of the SLC guns begins with a design of low electric field gradients, continues with the choice of the cleanest materials and their proper outgasing at high temperature bakes, and ends with careful monitoring of dark current, xrays and gas pressures. The assembly process requires extreme cleanliness to optimize HV performance as well as UHV performance. The chief diagnostics, the nanoammeter and the RGA, are used on the accelerator during beam operations to keep track of the dark current, the ultra high vacuum and any high voltage problem that might occur. At present there are three guns which can operate at 120 kV, with a total pressure of ~ 2×10^{-11} Torr and a dark current of 10-50 nA.

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