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The Polarized Electron Gun for the SLC

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Abstract

A new polarized electron gun for use on the SLC at SLAC has been built and tested. It is a diode gun with a laser driven GaAs photocathode. It is designed to provide short (2ns) pulses of 10 A at 160 kV at 120 Hz. The design features of the gun and results from a testing program on a new and dedicated beam line are presented. Early results from operation on the SLC will also be shown.

INTRODUCTION

The SLC Polarized Electron Source is based on a GaAs (or related III–IV semiconductor) photocathode. This type of electron source is not new and sources of this type have been used at SLAC [1] and elsewhere. CsF is deposited on the GaAs (100) crystal to achieve a negative electron affinity (NEA) surface. The interior of the gun must be held in a ultra-high vacuum condition to maintain the NEA of the photocathode. A spin polarized beam is brought off the photocathode by exciting electrons from only the top valence state into the conduction band with circularly polarized light. The electrons diffuse to the photocathode NEA surface, enter the vacuum and are accelerated by an applied electric field.

The SLC source differs from previous sources in the accelerator's requirements for high peak current. The source must put out 10^{11} electrons in the central 2ns portion of each pulse, a peak current of 10 A. To accomplish this the gun must run at a voltage of 160 kV. Maintaining the quantum efficiency of the photocathode while operating at high voltage is the central problemfor the design of the SLC gun.

GUN DESIGN

The design of the SLC gun is shown in Fig. 1, with the high-voltage end of the gun on the left of the drawing and the electron beam exiting to the right. The cathode electrode is held on a long support tube that is cantilevered from flanges on the high-voltage end through an alumina (AL-300 or AD-94) ceramic insulator. The photocathode, mounted on the end of its support tube, is held behind a 14-mm diameter hole in the cathode. The photocathode support tube is mounted on a bellows (shown inside the corona dome) so that it can be retracted 10 cm from the cathode electrode during bakeout and photocathode heat cleaning. The anode electrode, which is at ground potential, is mounted to the anode support that is attached to the main gun support flange. The vacuum chamber surrounds the anode and anode housing, and supports the vacuum pumps (not shown). The effusion cell cesium dispenser (not shown) is located down beam (to the right) of the anode. The cesiator is mounted on a bellows allowing it to be retracted when not in use, or inserted onto the gun axis so that cesium can be directed through the hole in the anode and deposited on the photocathode. For high-voltage operations the ceramic insulator and high-voltage corona dome are placed in 1 atm of SF_6.

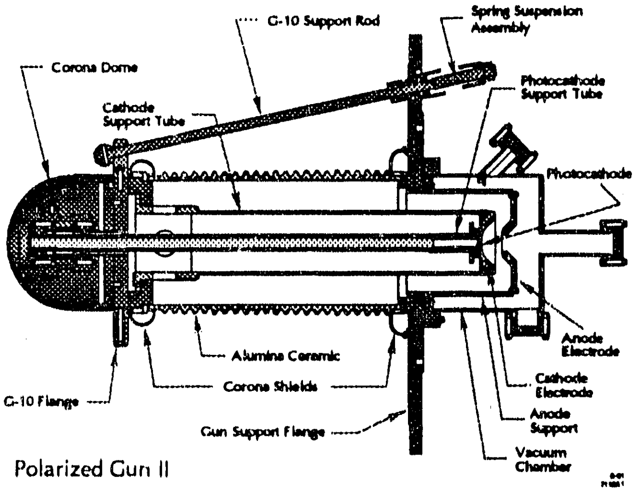

Figure 1. Elevation of the SLC polarized gun. Laser light enters, and electrons exit on the right. Negative high voltage is connected to the left-end corona dome and held off from the grounded anode and gun support by an alumina ceramic.

Three guns of this design have now been produced. Vacuum parts are made from 304L vacuum arc remelted stainless steel with low carbon content and fine grain structure. The electrodes are machined from 317L vacuum arc remelted stainless steel with a very low carbon content and few inclusions. The end of the photocathode support tube is arc cast high purity molybdenum for uniform heating of the photocathode during heat cleaning. The molybdenum is brazed to a short piece of Kovar that matches the molybdenum's coefficient of thermal expansion. The Kovar is then welded to a 304L stainless tube. All vacuum parts were outgassed in vacuum at 450°C prior to assembly. The guns were assembled in a class 1000 clean room to minimize contamination in the ultra-high vacuum volume.

ELECTRODE CONFIGURATIONS

The high current required to come from the SLC source places requirements on the perveance of the gun. Operating the source near the space charge limit is desirable to minimize beam intensity jitter. The surface fields on the cathode electrode must also be low to minimize electron field emission and breakdown, which cause gases to be evolved and can irreversibly contaminate the photocathode. The problem of field emission is made worse by the adsorption of cesium on the cathode surface during or

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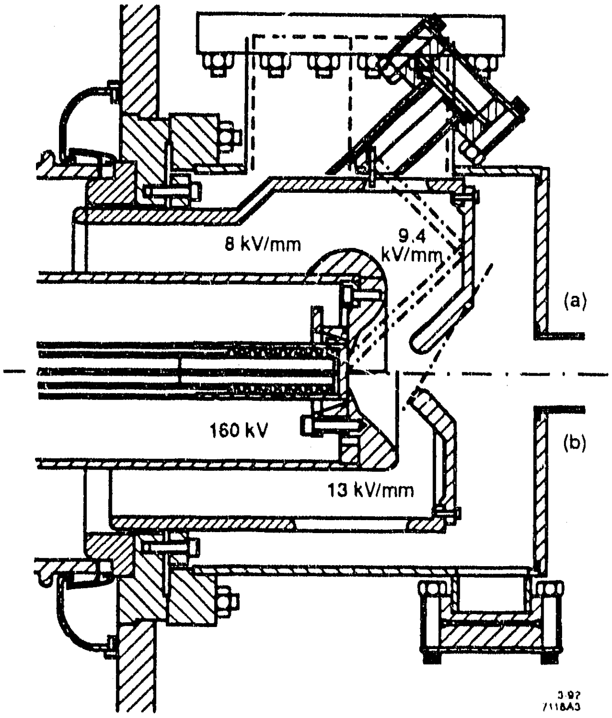

Figure 2. The lower half, (b), shows the design of the original electrode set. The photocathode sits at the centerline behind the cathode electrode. The upper half, (a), shows the new 'low field' electrode set. Light enters from the top right to illuminate the photocathode during activation.

after photocathode activation. These requirements on the cathode field strengths have led to two electrode structure designs.

The first design is shown in Fig. 2b (and in Fig. 1). The design was based on the electrodes used in the SLC thermionic gun [2] which routinely gives the needed beam current. The electrode structure was modeled using the program EGUN [3] which calculates the surface fields and the space charge limit of the structure. The perveance of this electrode configuration is 0.16 μpervs, giving a space charge limit of 10 A at 160 kV. The maximum field is 13 kV/mm on the outer edge of the cathode electrode. While fields of this strength can be held on stainless steel surfaces in vacuum, the proximity of the photocathode suggests that cesium will be deposited in the high field area.

A second electrode set was designed to lower the surface fields on the cathode electrode. The low-field electrode design, first suggested by W. Herrmannsfeldt, is shown in Fig. 2a. The perveance of this electrode configuration is approximately the same as the first. The maximum field is 9.4 kV/mm on the outer edge of the cathode electrode. The second, low field, electrode design (not shown in Fig. 1) is now installed in the third gun, and the first two guns are being retrofitted with the new design.

VACUUM PERFORMANCE

The maintenance of the ultra-high vacuum condition is performed by two pumps. The first is a Perkin Elmer differential ion pump [4], rated at 120 l/s. A D-I pump is chosen for its effectiveness with pumping argon and other noble gases. The ion pump is paired with an SAES non-evaporable getter (ST707) pump [5] rated at 200 l/s and operated at room temperature. The NEG pump has very good pumping characteristics at low pressures, holding the pumping speed at pressures below 10^{-11} mm and pumping CO and CO_2. It does not pump methane, which can be detrimental to the photocathode lifetime, nor noble gases. The NEG pump also pumps well in the range at 250°C, making it an effective pump during vacuum bakeout.

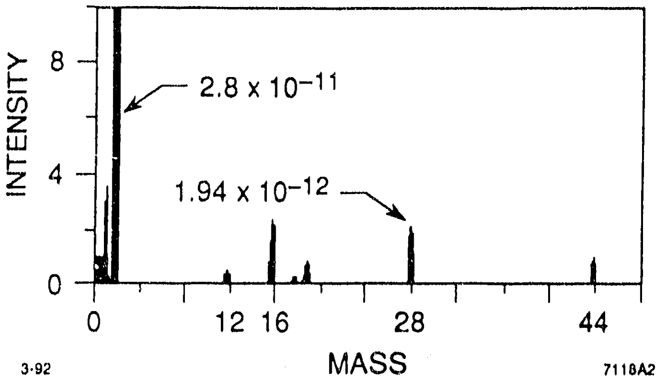

Figure 3. Residual Gas Analyser spectrum showing the partial pressure in the gun of H_2 (2.8×10^{-11} mm, off scale), of CO (1.9×10^{-12}) and of CO_2 (1×10^{-12}).

To monitor the vacuum levels in the gun, a Residual Gas Analyzer (RGA) [6] is attached. A typical RGA spectrum of gases in the gun is shown in Fig. 3. The hydrogen partial pressure is shown off scale and equal to 2.8×10^{-11} mm. The RGA spectrum shows small CO and CO_2 peaks at masses 28 and 44 respectively. The spectrum shown in Fig. 3 is very stable, and minute (10^{-13} mm) changes can be seen in the partial pressures, but the absolute value of the pressures is only accurate to within a factor of two. The peaks at mass 16 and 19 are attributed to surface effects in the analyzer head.

HIGH-VOLTAGE PERFORMANCE

The initial high-voltage performance given with either electrode set was good. The guns were processed to 180 kV and were able to hold 160 kV for extended periods without breakdown. The low-field electrode set processed up to voltage much more easily than did the original design, which required processing with nitrogen to reach voltage. After processing there was no evidence of dark current drawn by the guns at 160 kV, and no dark current at 180 kV for the gun with the low-field electrodes.

After high-voltage processing the photocathode is poisoned and must be replaced. This requires venting the gun vacuum volume with dry nitrogen and opening it to air. The gun is open with a N_2 purge for the ten minutes required to change the photocathode. The gun is then vacuum baked at 250°C for 100 hours. After this procedure the high-voltage processing is partially lost, and the gun shows high-voltage and vacuum activity as low as 140 kV. It is this behavior which sets the value of the operating voltage at 120 kV (space charge limit 6.5 A).

After repeated use of the guns (several photocathode changes and system bakeouts) the high-voltage behavior degrades significantly. The degradation seems to be dependant on photocathode cesiations. Eventually, one standard cesiation will degrade the performance such that the high voltage cannot be brought up to the operating level; high voltage and vacuum activity is seen at 80 kV or lower. The high-voltage performance can be regained by processing, but the processing destroys the photocathode. At this point the gun is no longer operational. We have one such gun which is being disassembled, cleaned and rebuilt to remove the cesium found throughout this gun.

PHOTOCATHODE PERFORMANCE

Testing with the new guns has been performed with GaAs photocathodes, zinc doped to 1–2 × 10^{19}/cc. The 18 mm diameter photocathodes are cut from a 3-inch wafer. The bandgap of GaAs is not well matched to the dye used in the SLC polarized source laser (715 nm.), but the GaAs material should give ~30% polarization. Matching the III-IV semiconductor bandgap to the laser wavelength should yield 40–45% polarization. GaAs(.87)P(.13) has been acquired for this purpose and activated to good quantum efficiency, but not yet tested in the guns.

In the gun the GaAs photocathode is activated in the following manner. The photocathode is heat treated to 620°C for one hour to remove oxides from the surface. The temperature of the GaAs surface has been measured with an infrared pyrometer active at 900 nm [7] and that temperature referenced to a thermocouple behind the photocathode. The cesium effusion cell is heated bringing the cesium reservoir to 100°C. The effusion cell is inserted to face the photocathode and the photocurrent, excited with a white lamp, is monitored. When the photocurrent peaks, the cesiator is retracted and NF_3 is let into the system through a variable leak valve to a pressure of 10^{-8} mm. Cesium and NF_3 are deposited in cycles in the so-called 'Yo-Yo' technique. With this technique we have been able to consistently achieve quantum efficiencies of 1–3%, measured with a 750 nm diode laser.

The quantum efficiency decreases with time, and can be characterized by an exponential with an increasing characteristic lifetime. A range of lifetimes from a few hours to hundreds of hours has been observed, with 10 to 40 hours being typical at room temperature (~20°C) when the quantum efficiency is .5–3%. When the quantum efficiency has dropped below a useful level, depositing a small amount of cesium (only) on the photocathode is sufficient to restore most of the original quantum efficiency. We are now establishing ways in which quantum efficiency can be stabilized.

Related to the quantum efficiency, there appears to be a limit on the current density which can be brought off the photocathode. We have observed a 'saturation' in photocurrent as laser intensity is increased. This limit has been observed when the photocathode is illuminated with 715 and 760 nm lasers, near the bandgap threshold, but not when a 533 nm laser is used. This current limit increases as quantum efficiency increases, but even at quantum efficiencies of 2–3% the limit is less than the space charge limit of the gun. This effect is not yet understood.

CONCLUSION

A new polarized electron gun for use on the SLC at SLAC has been designed and three guns have been fabricated. Considerable attention was paid to the vacuum aspects of the design, to the choice and selection of materials used, and to the fabrication process. The guns all exhibit very good vacuum characteristics, both when new and after repeated cathode changes and bakeouts. The high-voltage performance of the gun, however, is problematic. While a gun's initial high-voltage performance appears satisfactory, it has proven impossible to reach full voltage with a fresh photocathode. High-voltage performance after repeated photocathode activations is further degraded until the gun is unusable. We are pursuing two improvements to the high-voltage performance; an insulator with a resistive titanium chromium oxide coating to reduce static charge buildup on the insulator, and a segmented insulator which is shielded from the high-voltage cathode support tube. It is not clear whether either of these improvements will alleviate the effects of excess cesium in the gun.

The quantum efficiency of the photocathode might also be improved. In a separate cathode testing system, photocathodes are introduced into the vacuum volume through a load lock. In this system GaAs and GaAs(.87)P(.13) photocathodes have been activated to 14% quantum efficiency at 750 nm. It is suspected that subjecting photocathodes to high temperature bakeouts degrades their performance. A high initial quantum efficiency would decrease the mean time between cesium depositions, thus prolonging the lifetime of the gun. High quantum efficiencies might also alleviate the current density limit, giving increased beam currents. We are working on a load lock system for use on the gun in which all activations would take place in a separate chamber outside the gun vacuum volume. This will minimize the amount of cesium introduced into the gun, will allow the photocathode to be changed after high-voltage processing without venting, and should lead to high quantum efficiencies and long gun lifetimes.

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