

## Performance of the SLC Polarized Electron Source with High Polarization\*

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### Abstract

For the 1992 operating cycle of the SLAC Linear Collider (SLC), the polarized electron source (PES) during its maiden run successfully met the pulse intensity and overall efficiency requirements of the SLC. However, the polarization of the bulk GaAs cathode was low (~27%) and the pulse-to-pulse stability was marginal. We have shown that adequate charge for the SLC can be extracted from a strained layer cathode having  $P_e \sim 80\%$  even though the quantum efficiency (QE) is  $< 1\%$ . The recent addition of a separate chamber to the PES—which allows cathodes to be loaded into the gun after the vacuum bake and after high voltage (HV) processing without breaking vacuum—increases the reliability for achieving an adequate photoelectron yield. A new SLAC-built pulsed Ti:sapphire laser permits operation of the PES at the required wavelength with sufficient power to fully saturate the yield, and thus improve the  $e^-$  beam stability. The performance of the PES during the 1993 SLC operating cycle with these and other improvements is discussed.

### I. INTRODUCTION

In 1992, during the first SLC run with a polarized beam, the SLC performance was an impressive improvement over previous years. The luminosity of the accelerator and the efficiency of the detector were improved sufficiently for the SLAC Large Detector (SLD) to log over 10,000  $Z^\circ$ s with an average electron polarization at the Interaction Point (IP) of 23% during a run of approximately four months. The average (best) luminosity achieved by the end of the run was 18 (25)  $Z^\circ$ /hour. The goals for 1993 were to achieve at least 50,000  $Z^\circ$ s on tape with an electron polarization  $> 35\%$  at the IP. To meet these goals, it was estimated that the average (peak) luminosity should be about 23 (30)  $Z^\circ$ /hour. As shown in Table 1, the SLC/SLD are well on the way to meeting these goals. As will be discussed in more detail below, the polariza-

tion has been increased to  $> 60\%$  at the IP, and the average (peak) luminosity is now about 35 (45)  $Z^\circ$ /h, or in excess of 500  $Z^\circ$ /day.

For 1993, the SLC peak luminosity has been improved primarily by reducing the betatron coupling in each of the Damping Rings (DR) to produce flat beams. In addition, the average luminosity has been given an added boost by careful attention to reliability details, leading to a significant increase in efficiency. To improve the polarization, the energy of the  $e^-$  DR was increased to produce the correct spin precession to the linac-to-ring (LTR) spin rotator, thus reducing a 5% (relative) depolarization effect to  $\sim 2\%$ . However, the primary reason for the increased polarization of the electron beam is the inauguration in the PES of specially designed cathodes that remove the degeneracy at the  $\Gamma$  point between the heavy-hole and light-hole valence bands. Photoexcitation of such cathodes, using circularly polarized light of the proper wavelength, produces highly polarized electrons.

### II. CATHODES FOR HIGH POLARIZATION

The theoretical upper limit for the polarization of photoelectrons from bulk-grown NEA GaAs is 50%. Typically, the actual polarization is much lower unless very thin active layers or cryogenic temperatures are used. For 1992, the SLC PES operated with a bulk GaAs cathode at room temperature, resulting in a polarization at the source of only 27% [1].

Highly polarized electrons from photocathodes have been the focus of efforts at SLAC and other laboratories for many years. The first demonstration of success was at SLAC [2] in 1991, followed soon thereafter by similar results at Nagoya [3]. The technique employed is to introduce a uniaxial tensile strain in the growth direction by growing the active layer on a substrate with an appropriately smaller lattice constant. Above a certain critical thickness, the strain thus induced will decrease, so the active layer must be kept no thicker than a few hundred nanometers.

A crystal cut from an MOCVD-grown [4] 2-inch diameter wafer having a 300-nm active (strained) layer of GaAs(100), Zn-doped to  $5 \times 10^{18} \text{ cm}^{-3}$  and grown on a  $2.5 \mu\text{m}$  p-GaAs<sub>0.76</sub>P<sub>0.24</sub> sublayer, was measured at SLAC to have a peak polarization of  $\sim 80\%$  at  $\sim 860 \text{ nm}$  (room temperature) [5,6]. However, the low intensity QE measured at low voltage was only  $\sim 0.1\%$ , which gave rise to concern that it might be difficult to extract the high peak charge needed for the SLC (10 nC per microbunch in the present mode of operation).

A second crystal cut from the same wafer was tested at HV in the SLC gun [7] in a laboratory system having a high power laser tuned to 850 nm, but at present having no polarimeter. The saturated charge (i.e., the maximum charge for high laser power) was found to scale linearly with

|                            | Performance |      | 1993  |                  |             |
|----------------------------|-------------|------|-------|------------------|-------------|
|                            | 1991        | 1992 | Goals | Performance      |             |
| $Z^\circ/\text{h}$ typical |             |      | 18    | 23               | 35          |
| $Z^\circ/\text{h}$ peak    |             |      | 25    | 30               | 45          |
| $Z^\circ/\text{day}$ peak  |             |      | 400   | 550              | 600         |
| $Z^\circ$ total            | 370         | 1 K  | 11 K  | $> 50 \text{ K}$ |             |
| Pe @ IP                    | 0           | 0    | 23%   | $> 35\%$         | $\sim 60\%$ |
| Pe @ Source                | 0           | 0    | 27%   |                  | $\sim 80\%$ |

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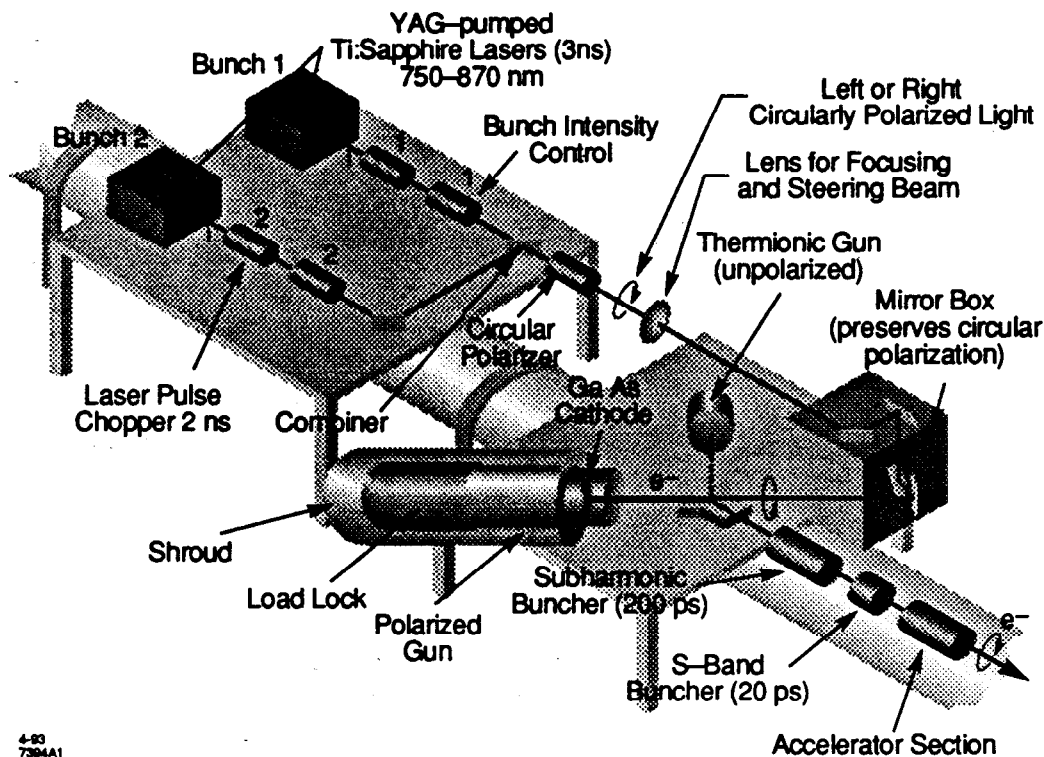


Figure 1. Schematic of the SLC PES for the 1993 SLC/SLD run.

cathode bias, whereas for a low intensity laser, the log of the photocurrent scaled as the square root of the voltage (the expected Schottky effect) [8]. A saturated charge of 19 nC, very close to the space charge limit of  $\sim 21$  nC, was achieved at 120 kV when the low intensity QE was 1% measured at 830 nm and 120 kV. The improvement in QE was probably due to the use of a load-lock system, as described later. This crystal, together with a third from the same wafer was in the cathode tray of the load lock when the polarized source was installed at the SLC for the 1993 run.

### III. RECENT POLARIZED ELECTRON SOURCE IMPROVEMENTS

The pulsed dye laser used in the 1992 run was limited by power and lifetime requirements to 715 nm, a wavelength too low to permit any polarization gain with the new cathodes. A new Nd:YAG pumped Ti:sapphire laser, Q-switched and cavity-dumped, designed and built at SLAC [9], was installed for this run. This laser, together with associated beam transport optics, provides up to 100  $\mu$ J energy at the cathode in each 2.0 ns FWHM micropulse at wavelengths up to 870 nm.

The addition of a load lock that allows a photocathode to be introduced into the gun chamber after the chamber is baked and HV processed has proven to be a major step in improving the PES performance and reliability [10]. Up to four cathodes can be stored at one time in the load-lock system.

The cathodes are activated in the load-lock system, in part to avoid Cs contamination in the gun itself. Cathode activation

and/or switching of cathodes takes about 8 hours, followed by a period of 10–20 hours in which the gun shroud is purged to remove water vapor before operating at HV. For simple addition of small amounts of Cs to the operating cathode, Cs channels [11] that encircle the  $e^-$  beam are located in the gun chamber just downstream of the anode. The Cs channels are operated remotely through the SLC Control Program (SCP). A schematic of the present PES is shown in Fig. 1. A cross section of the gun is shown in Ref. [12].

### IV. 1993 POLARIZED ELECTRON SOURCE PERFORMANCE

The polarization of the  $e^-$  beam could be measured at 50 GeV by a Møller polarimeter at the end of the linac and by a Compton polarimeter at the IP. The latter was sensitive to the tuning of the Arcs. The wavelength of the PES laser and the Compton polarization were monitored continuously. A sample is shown in Fig. 2. Combined with a Møller measurement made early in the run with the  $e^-$  DR bypassed, the source polarization was found to peak at  $\sim 865$  nm (cathode at  $-6^\circ\text{C}$ ) with  $P_e \sim 80\%$ .

In its first 10 weeks of operation with a strained layer cathode, the PES was able to provide a highly polarized  $e^-$  beam for the SLC  $>95\%$  of the time. During the run, the charge limit effect [13] was not a serious limitation [14], although the low-intensity QE following a cesiation touchup was only  $\sim 0.5\%$  measured at 830 nm and 120 kV.

The QE was monitored by detecting (using a nanoammeter attached to the HV electrode) the photocurrent drawn

from the cathode by a modulated 830 nm diode laser (gated off during the beam pulse) attached to a side window of the gun. The nanoammeter was powered and also connected to the SCP through an optical link.

The  $e^-$  intensity was controlled through a feedback system that varied the size of the Ti:sapphire laser spot on the cathode. The laser itself was operated at very high energy so as to keep the cathode always completely saturated. In this manner the  $e^-$  pulse-to-pulse intensity jitter could be kept  $\sim 1\%$ , although the laser energy jitter was often  $>3\%$ . The charge limit did reduce the maximum charge available as a function of cathode surface conditions.

The overall pressure in the gun was  $\sim 10^{-11}$  Torr, dominated by  $H_2$ . As shown in Fig. 3, the rate of decrease of the low intensity QE was not affected the charge extracted from the gun. The QE was found to decrease by  $<0.05\%/day$ . The cathode lifetime was probably extended in this vacuum system by operating the cathode at  $-6^\circ C$  and by the success of the HV processing that reduced the dark current (cathode current at

120 kV with all lasers blocked) to  $<50$  nA [15]. To maintain the required charge, cesium was added in intervals of  $\sim 3$  days.

It was a simple matter to cesiate from the SLC Control Center using the SCP to lower the HV to 1 kV, then to operate the channel cesiator at a fixed 4 A for  $\sim 4$  minutes. To extend the cesiation intervals, the cathode was usually cesiated until the photocurrent dropped  $\sim 20\%$  lower than its peak value. The whole operation took  $\sim 25$  minutes.

## V. NEXT DEVELOPMENTS

Three new developments may improve the source performance even further in the near future. One of the four SLC polarized guns has been modified to double the area of the semiconductor cathode in order to increase the charge limited current. This will be tested soon in the laboratory. Operating the gun at 150 kV instead of 120 kV should also increase the photoelectron emission 25% when charge limited.

Source polarizations  $>90\%$  can be achieved with even thinner strained-layer cathodes [6]. The charge limit for such cathodes is under investigation.

Within the next few months, a Mott polarimeter will be added to the SLC high beam intensity testing system allowing a crystal to be fully qualified for  $P_e$ , QE, charge limit, and lifetime before this same crystal is installed in the operating SLC gun.

## VI. REFERENCES

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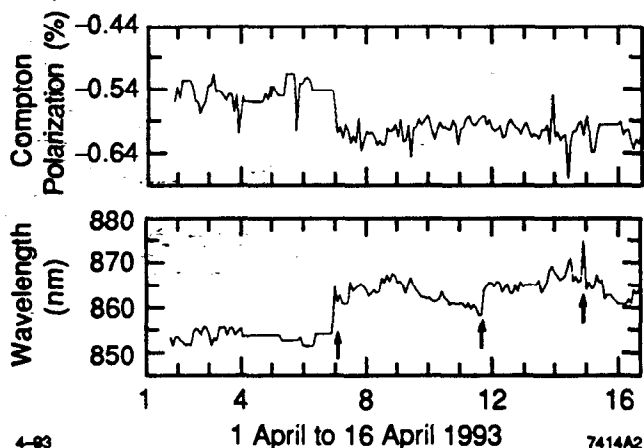


Figure 2. Comparison of PES laser wavelength and Compton polarization over a period of 16 days. The PES wavelength was deliberately changed on April 6, 11, and 14: 853 $\rightarrow$ 865 nm, 859 $\rightarrow$ 864 nm, and 870 $\rightarrow$ 864 nm, respectively.

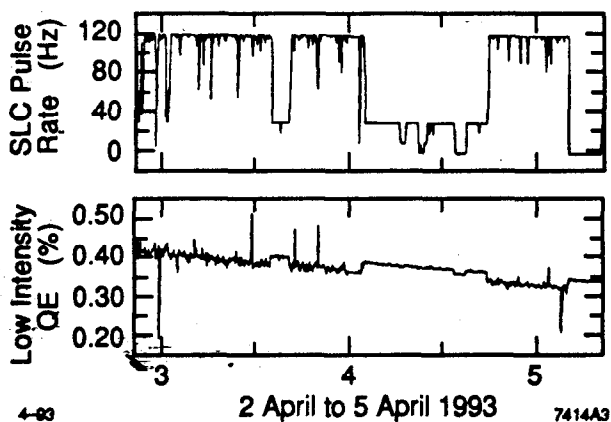


Figure 3. Comparison of the low-intensity QE monitored through a period of  $\sim 15$  hours when the SLC macropulse rate was dropped from the usual 120 Hz to 30 Hz. The offset in the QE is probably an artifact of the instrumentation.