SLAC-PUB-6918
June, 1995

THE SLAC POLARIZED ELECTRON SOURCE[*]

H. TANG, R. ALLEY, J. CLENDENIN, J. FRISCH,
G. MULHOLLAN, P. SAEZ, D. SCHULTZ, and K. WITTE

Stanford Linear Accelerator Center, Stanford, CA 94309, USA

Abstract

The SLAC polarized electron source employs a photocathode DC high voltage gun with a loadlock and a YAG pumped Ti:sapphire laser system for colliding beam experiments or a flash lamp pumped Ti:sapphire laser for fixed target experiments. It uses a thin, strained GaAs(100) photocathode, and is capable of producing a pulsed beam with a polarization of ≥80% and a peak current exceeding 10 A. Its operating efficiency has reached 99%. The physics and technology of producing high polarization electron beams from a GaAs photocathode will be reviewed. The prospects of realizing a polarized electron source for future linear colliders will also be discussed.

Invited talk presented at the International Workshop on Polarized Beams and Polarized Gas Targets

Cologne, Germany, June 6–9, 1995

1 Introduction

Polarized electron sources based on photoemission from negative electron affinity (NEA) GaAs-type semiconductor photocathodes have seen wide-spread application in solid state physics as well as in high energy physics since its concept was first proposed in the 1970s [1,2]. In addition to the capability of easy and fast polarization direction reversal without affecting other beam properties, which is so important for nearly all types of experiments that require polarized electron beams, NEA photocathode based polarized electron sources possess other highly desirable characteristics. These include high brightness, narrow energy spread of the emitted beam, and the flexibility of modulating the beam intensity with an arbitrary time structure by controlling the photoexcitation light. These attributes have also made them attractive as electron sources in general that require no spin polarization.

At SLAC, development of the first GaAs-based polarized electron source began in 1975 [3]. That source employed a bulk GaAs cathode housed in a diode-structure gun with an operating high voltage of 65 kV and a flashlamp pumped dye laser tuned to a wavelength corresponding to the polarization peak of the cathode. In 1978, it was successfully operated on the linear accelerator for the landmark parity violation experiment [4]. During the run, the source delivered a pulsed electron beam of pulsewidth 1.5 µs with an average polarization of 37% and a typical beam current of 15 mA at the experiment at a repetition rate of 180 Hz. The overall operating efficiency of the source was about 75%. This successful operation demonstrated the superior characteristics of the NEA photocathode polarized electron source in terms of both beam quality and operational ease and efficiency over other existing types. Thereafter, GaAs polarized sources gained application in other high energy accelerator laboratories including Bonn, MIT/Bates, and Mainz and in solid state physics [5] as well.

The development of a highly reliable and efficient polarized electron source for the Stanford Linear Collider (SLC) [6] was difficult and took a long time. The SLC was designed to collide a single bunch of 5×10^{10} polarized electrons at the interaction point with an identical bunch of unpolarized positrons at a center of mass energy of about 91 GeV to produce Z° bosons. The source was required to produce two 2-ns pulses of about 62 ns apart with an intensity of up to 1×10^{11} electron/pulse at a repetition rate of 120 Hz. The first pulse must be polarized, whereas the second is used to produce positrons and thus has no polarization requirement. While the requirement on the integrated pulse intensity was not unusual as compared with those of other experiments, the pulse beam current for the SLC is on the order of many amperes at the source, which is at least an order of magnitude higher than the capability of any such sources ever constructed. Thus, the electron gun must be operated at a high voltage of over 100 kV to push up the inherent space charge limit of the gun. The severe high voltage operating condition, however, presented a hostile environment for the operation of the highly delicate NEA photocathodes. It took several years of intensive research and development effort on the gun and the laser as well before a reliable, high intensity polarized electron source was finally realized in 1992.

---

[*] Work supported by Departement of Energy contract DE-AC03-76SF00515.

Since its first operation for the SLC in 1992 [7], the new polarized electron source [8] has provided high quality electron beams to many colliding beam and fixed target physics runs for about 30 months with an overall efficiency better than 95%. The peak operating current exceeded 6 A during the 1994-1995 SLC run, while the polarization averaged about 80%. The maximum beam polarization during a low current fixed target run reached 86%. Minimal maintenance has been required for operating the source. In the next few sections, we will first review the physics and technology of producing polarized electrons from a GaAs photocathode. A description of the present SLAC high intensity polarized electron source and its performance characteristics then follows. Finally, the prospects for a polarized electron source for the next generation of linear colliders will be discussed.

2 Physics and Technology of GaAs Photocathodes

2.1 *Optical Spin Orientation*

GaAs is a direct gap semiconductor with a minimum separation of E_g between its valence and conduction bands at the Γ point in momentum space. Fig. 1 depicts the structures of the top valence bands and the bottom conduction band in terms of energy versus momentum near the Γ point for uniaxially tensily strained GaAs. Spin-orbit interaction splits the $P_{1/2}$ band from the $P_{3/2}$ band, which is normally quadruply degenerate at the Γ point in strain-free GaAs. In strained GaAs, this four-fold degeneracy is partially lifted, leading to a splitting (δ) between the heavy-hole ($m_j=\pm3/2$) and light-hole ($m_j=\pm1/2$) bands at the Γ point. The splitting is approximately proportional to the lattice strain, and for uniaxial tensile strain the heavy-hole band lies on top.

The band structure of GaAs allows for direct optical transition by electrons from the valence bands into the conduction band with photon energies close to E_g. For circularly polarized light with positive helicity, σ^+, the allowed transitions between the three valence bands and the conduction band are shown in Fig. 1. Their relative transition probabilities are determined by the Clebsch-Gordon coefficients and are also marked in the figure. If the excitation photon energy is chosen to be between E_g and $E_g+\delta$, only those electrons in the heavy-hole band may be promoted into the conduction band. In this case, the excited electrons should all be polarized in the same direction, i.e., their polarization should be 100%. It is easy to see that the theoretical limit on the electron polarization in strain-free GaAs is 50%. The strain induced splitting between the heavy-hole and light-hole bands permits selective excitation from the heavy-hole band only, which is crucial for yielding polarizations beyond 50%. In practice, however, instead of being sharply defined, the energy bands in a GaAs crystal are broadened due to crystalline defects and thermal agitation. Therefore, to achieve polarizations significantly higher than 50%, the strain must be sufficiently large such that the overlap between the broadened heavy-hole and light-hole bands is small.

2.2 *Polarized Photoemission from NEA GaAs Photocathode*

Once excited into the conduction band, the electrons quickly thermalize to the bottom of the conduction band and diffuse to the surface. While these electrons will normally remain inside the GaAs crystal as the vacuum level is about 4 eV high, efficient escape is possible in a p-type doped GaAs cathode whose emitting surface is treated to have an NEA. Specifically, NEA refers to the condition that the vacuum level is below the conduction band minimum in the bulk, permitting electrons to escape into vacuum. This situation is illustrated in Fig. 2. The realization of the NEA condition is a result of a work function lowering thin surface layer formed by an alkali and an oxidizer, typically Cs and F or O, and the downward band bending near the surface in a *p*-type, such as Zn, doped GaAs.

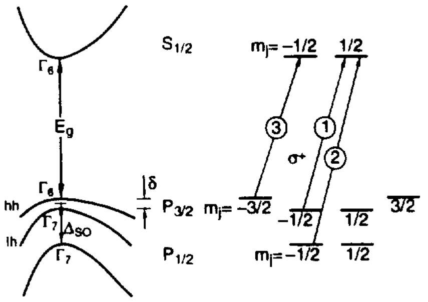

Fig. 1: The relevant conduction and valence energy bands of uniaxially tensily strained GaAs near the Γ point (zero momentum) in momentum space, and the relative optical transition probabilities for excitation with σ^+ light.

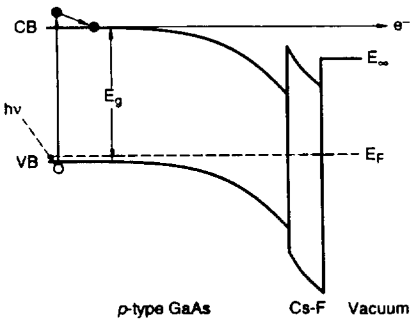

Fig. 2: The downward band bending near the surface of a *p*-doped GaAs cathode and the addition of a Cs-F layer on the surface drops the vacuum level to below the conduction band minimum in the bulk, leading to NEA.

In order to achieve NEA, a GaAs cathode must reside in an ultrahigh vacuum system. The activation process that yield an NEA surface consists of the following steps: (1) Prepare an atomically clean surface by heating the cathode to a temperature just below the congruent point for GaAs which is near 660 °C. At SLAC, heat cleaning is performed at 600 – 610 °C for a duration of about 1 hr; (2) While monitoring the photocurrent with the combination of a white light source and a Helium-Neon laser (633 nm), apply Cs to the clean surface until the photocurrent peaks; (3) Finally, apply Cs and an oxidizer either simultaneously or alternatively until the photocurrent is maximized. We use NF_3 as the oxidizer while many laboratories use O_2 instead. For the Cs source, we have gradually switched from Cs effusion cells to channel dispensors that are much easier to operate.

In addition to the spin polarization, another important parameter that characterizes an NEA GaAs photocathode is the quantum efficiency (QE), defined as the number of emitted electrons normalized by the number of incident photons. The QE is determined by three factors: optical absorption efficiency, probability of diffusing to the surface, and surface escape probability [9]. For a thin GaAs cathode, such as the highly strained 100 nm cathode used at SLAC, its QE essentially scales with the cathode thickness normalized by the absorption depth, which strongly depends on the excitation photon energy near the band gap threshold and can be as large as many microns. Thus, due to inefficient optical absorption, the QE of a thin strained GaAs cathode for maximum electron polarization can be up to two orders of magnitude lower than the bulk cathode's QE, typically on the order of 10%.

The polarization of the emitted electrons is generally lower than the initial polarization of the photoexcited electrons in the conduction band due to depolarization effects during the photoemission process [10]. Electrons that spend less time inside the crystal have a smaller probability to be depolarized and therefore have a higher polarization. Electrons that spend more time in the crystal generally have lower energies and are less likely to escape when the NEA condition, or the QE, deteriorates with time. Therefore, for a given cathode, there is in general a negative correlation between the spin polarization of emitted electrons and the QE.

2.3 High Polarization Photocathode R&D

As discussed earlier, enhanced photoelectron spin polarization, i.e., >50%, using GaAs is possible only if the degeneracy between the heavy-hole and light-hole bands is removed. This may be accomplished by lowering the crystalline symmetry of the GaAs lattice. One approach is to introduce a lattice deformation in the GaAs crystal, and the other is to create an artificial structure with a lower symmetry. The strained-lattice cathode [11] falls into the former category, whereas the superlattice [12] belongs to the latter type. Both are artificially engineered structures that require a molecular beam epitaxy (MBE) or a metal-organic chemical vapor deposition (MOCVD) system to perform the epitaxial growth process.

In 1991, Maruyama et al at SLAC [11] reported the first observation of enhanced spin polarization from a NEA strained $In_{0.13}Ga_{0.87}As$ photocathode. The uniaxial compressive strain in the $In_{0.13}Ga_{0.87}As$ layer is realized by growing on a slightly lattice-mismatched GaAs substrate. The spin polarization reached about 70%, significantly higher than the 50% limit of strain-free GaAs-type photocathodes. Continued effort in photocathode R&D at SLAC [13] and Nagoya University [14] led to an optimized structure of biaxially compressively strained GaAs on $GaAs_{1-x}P_x$ that yielded electron polarizations over 80%.

The photocathodes presently employed in the SLAC polarized electron source are the optimized 100 nm strained GaAs doped with Zn to a density of 4–6×10^{18} cm^{-3} grown on $GaAs_{0.72}P_{0.28}$. These materials were grown by the Spire Corporation [15] using the MOCVD technique following the procedures outlined below. A 0.25 μm thick *p*-type GaAs buffer layer was first grown on a vicinal (100) p-type GaAs substrate oriented two degrees towards the [110] direction. In order to produce a strain relieved $GaAs_{0.72}P_{0.28}$ layer on GaAs, a 2.5 μm thick $GaAs_{1-x}P_x$ layer was grown with the phosphorous fraction, x, gradually increasing from 0 to 0.28 to avoid an abrupt lattice mismatch, followed then by the growth of an additional 2.5 μm thick $GaAs_{0.72}P_{0.28}$ with a fixed phosphorous fraction. Finally, a 100 nm lattice-mismatched GaAs layer, which serves as the active photoemission layer, was grown with the desired Zn doping density. The lattice mismatch introduces a biaxial compressive strain in the 100 nm GaAs layer in the (100) growth plane, or equivalently, a uniaxial tensile strain along the growth direction.

The spectra of the electron spin polarization and QE for a SLAC 100 nm strained NEA GaAs photocathode at room temperature measured in a low-voltage ultrahigh vacuum system are shown in Fig. 3. Typical of the SLAC 100 nm strained GaAs cathodes, the polarization peaks around 80% in the wavelength range of 850 – 860 nm with a QE on the order of 0.1%.

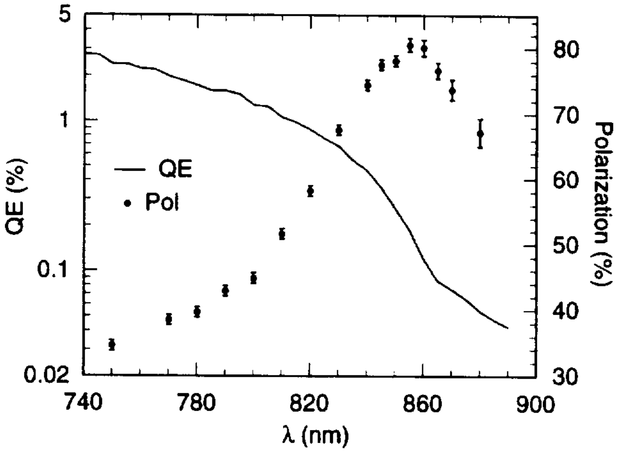

Fig. 3: Quantum efficiency and electron polarization as a function of wavelength for a SLAC 100 nm, 5×10^{18} cm^{-3} Zn-doped photocathode activated to NEA with Cs and F. The cathode was at room temperature and biased at −22 V.

Despite the low QE inherent to such a cathode, low duty factor, high power pulsed lasers were developed at SLAC to drive the cathode to produce the required high intensity, high polarization electron beam. For high duty factor or cw beam accelerators such as at CEBAF or MIT/Bates that also require relatively high beam current, however, the low efficiency of such a cathode may render it unusable due to the lack of a sufficiently high powered laser. The poor QE may be remedied by adding a properly engineered distributed Bragg reflector behind the 100 nm active layer to boost the optical absorption efficiency in the active layer at the peak-polarization wavelength. Enhancement of the QE by a factor of ten has been reported for a 100 nm strained GaAs cathode incorporating such a Bragg reflector [15]. A thin GaAs/AlGaAs superlattice cathode, which has a lower polarization (about 70%) but an order of magnitude higher QE [17], may be a good alternative for these high duty factor accelerators as well.

2.4 New Phenomena of Polarized Photoemission

A. Charge Limit

When the QE of a GaAs cathode drops below a critical value, the maximum charge that can be produced from the cathode within a 2-ns pulse using photons of energy close to E_g becomes limited by its intrinsic and surface properties rather than by the space charge limit [18]. This maximum charge is referred to as the cathode's charge limit under the specific QE condition. For a given cathode at a fixed high voltage, the charge limit is approximately proportional to the QE. It also strongly depends on the high voltage at which the cathode is biased. In addition, the charge limit has a memory effect, i.e., the charge limit for a pulse closely following another is further decreased. The time scale of the memory effect is on the order of 100 ns for the 5×10^{18} cm^{-3} Zn-doped 100 nm strained GaAs cathodes but decreases very rapidly with increasing doping density. The charge limit phenomenon is a manifestation of electrons excited earlier suppressing the emission of subsequently excited electrons within a time scale defined by the memory effect. The suppressed emission is caused by a momentary increase in the surface work function as a result of a decrease in the surface band bending due to the accumulation of excited electrons at the surface that fail to escape. Using this surface photovoltaic effect model, Herrera-Gomez and Spicer performed a numerical simulation of the charge limit phenomenon [19].

In principle, a charge limit always exists for any NEA GaAs photocathode regardless of its QE, thickness, and strain. For a sufficiently high QE, the charge limit exceeds the maximum value set by the space charge limit. In this case, the charge limit becomes unobservable and, therefore, will not limit the performance of the cathode. It is also worth noting that the quantum yield defined by the number of emitted electrons over the number of photons absorbed in the active layer, rather than the commonly used QE, is the more appropriate parameter for discussing the charge limit. The significance of the charge limit effect for a high intensity polarized electron source is that it sets a lower limit on the cathode's QE below which the source fails to meet the intensity requirement. It also sets a limit on the usable range of the laser pulse energy.

B. QE Anisotropy

If linearly polarized light is used to illuminate a strained GaAs(100) photocathode at normal incidence, the QE shows a dependence on the azimuth angle of the polarization plane [20], i.e., the QE is anisotropic. The QE varies sinusoidally in azimuth, and assumes maximum and minimum values along the [01–1] and [011] crystalline axes, respectively. Over the wavelength range in which the electron polarization is enhanced, the QE anisotropy shows an excellent correlation with the polarization. The QE anisotropy originates from an in-plane strain anisotropy, which leads to modified heavy-hole and light-hole bands that are no longer purely the $m_j=\pm3/2$ or $m_j=\pm1/2$ states. The maximum QE anisotropy in a strained GaAs cathode may reach 15%, which is rather substantial.

Most experiments that use a polarized electron beam require the polarization sign to be changed on a pulse-to-pulse basis without affecting other beam parameters, such as intensity. Because of the practical difficulty of obtaining pure ciucularly polarized light, the existence of a QE anisotropy may result in a sizable intensity asymmetry between the opposite polarization signs due to the small linear component contained in experimentally generated circularly polarized light. In this case, it requires careful tuning of the two circular polarization states of the excitation light to minimize the intensity asymmetry.

3 The SLAC Polarized Electron Source

3.1 *Lasers*

Two laser systems, one for SLC short pulse operation (2 ns) and the other for fixed target long pulse operation (100 ns – 10 μs), were developed to drive the photocathode gun [8]. Titanium-doped sapphire was chosen as the active material for both systems as its large wavelength range (700 nm – 880 nm) excellently matches the requirements of GaAs photocathodes.

The SLC laser system employs two commercial frequency-doubled Nd:YAG lasers operated at 60 Hz to pump two Ti:sapphire cavities to produce two 2-ns pulses at 120 Hz (see Fig. 4). The first cavity is tuned to a wavelength around 845 nm to yield the highest polarization from the cathode, whereas the second, lagging the first by about 62 ns, operates at about 790 nm to take advantage of the cathode's increased capability of charge production. Each cavity is Q-switched and cavity-dumped by an intracavity Pockels cell. The output pulse from the cavity, a fast rise-time and fall-time pulse of approximately 3.5 ns in length, is shaped with a fast (2ns FWHM) Pockels-cell pulse chopper used with two crossed polarized. The intensity is controlled with a longer pulse (30 ns) Pockels cell. The beams from the two cavities are combined with a polarizing splitter. The circular polarization sign of the production bunch is controlled with another Pockels cell. Adjustable telescopes

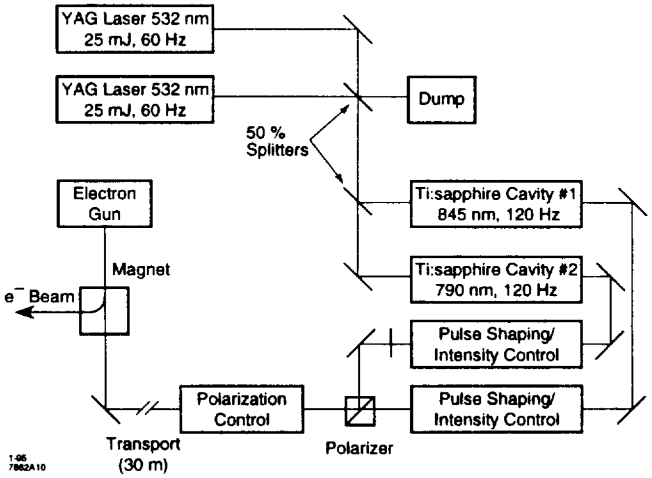

Fig. 4: The SLC laser system consists of two Ti:sapphire cavities pumped by two 60 Hz pulsed Nd:YAG lasers to produce two 2-ns laser pulses at 120 Hz for charge production from a NEA photocathode.

in the optical transport allows independent steering and focusing of the two bunches onto the cathode.

Feedback loops on the Nd:YAG lasers, the Ti:sapphire cavities, and the intensity controls maintain the long-term stability of the laser. A feed-forward system which measures the Nd:YAG energy on each pulse and, on the same pulse, adjusts the timing of the high voltage Q-switching pulse to compensate for changes in gain in the Ti:sapphire cavity further improves the intensity stability. At present, the root-mean-squared (rms) intensity jitter for both laser bunches at the cathode is typically 1%, which adequately meets the SLC requirement. Both Ti:sapphire lasers are capable of delivering up to 120 μJ to the cathode.

A falshlamp-pumped Ti:sapphire laser, which does not use Q-switching and cavity dumping, is used for long-pulse fixed target experiments. This laser also operates at 120 Hz. The output from the laser is an approximately 10 μs pulse, out of which a pulse of the desired length ranging from 100 ns to 2.5 μs is chopped with a Pockels cell. The output is a square pulse with an intensity jitter of 2–3% rms. The flashlamps have a lifetime of $1–2\times10^8$ shots, or 10–20 days.

3.2 Photocathode Gun and Loadlock

Vacuum and high voltage are the two key issues in the gun design and development. To be able to produce the high intensity beam for the SLC, the gun must operate at a sufficiently high voltage so that the space charge limit is comfortably above the operating level. At the same time, the gun must provide an ultrahigh vacuum at the operating high voltage for an NEA GaAs photocathode to perform reliably. Thus, the key design parameters for the gun are: $<1\times10^{-12}$ Torr of total vacuum (excluding H_2) and <50 nA of dark current at the operating high voltage of 120 kV.

The gun [8] has a Pierce diode structure and follows the conventional design for thermionic-cathode guns in which the cathode electrode is supported by a large ceramic insulator which also forms a major portion of the vacuum wall. Since the cathode electrode is the primary source for field emission at high voltage, the maximum field on the surface of the electrode is limited to 7 MV/m at 120 kV. The cathode and anode electrodes were fabricated from low carbon content and low inclusion density stainless steel. After chemically cleaned and hydrogen fired to 1050 °C for 10 min, the electrodes were polished with diamond paste to a 1-μm finish. Extreme care was taken in maintain the cleanliness of the electrodes and other components that see high fields. The assembly was done in a class 100 clean room to minimize dust contamination. A cross section of the gun is shown in Fig. 5.

All materials used in the construction of the gun were chosen for ultrahigh vacuum compatibility, and were cleaned and vacuum fired at 450 °C prior to assembly. The gun employs a 120 l/s Perkin-Elmer differential ion pump and a 200 l/s SAES Getters non-evaporable getter (NEG) pump. Both pumps have excellent conductance to where the photocathode resides. Following assembly, the gun was baked at a temperature close to 250 °C for about 100 hours.

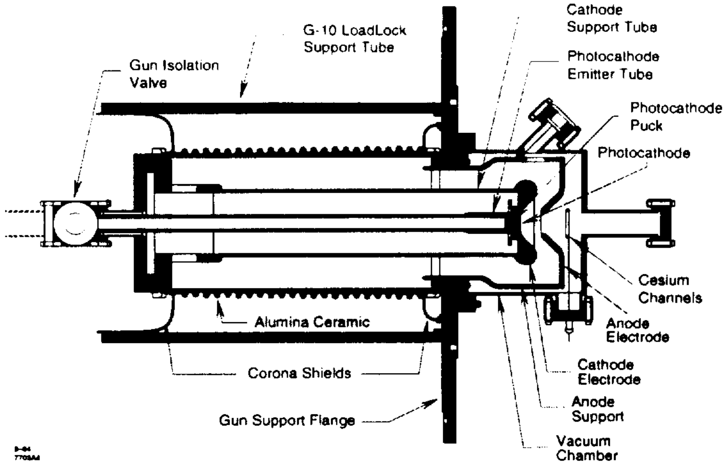

Fig. 5: Longitudinal cross section of the SLAC polarized electron gun. The loadlock is attached to the gun from the left side.

The use of a loadlock [8] for the gun greatly improved the reliability of the source operation. The loadlock performs the essential duties of introducing new cathodes into the system without breaking either the gun or loadlock vacuum, heat cleaning and activating cathodes, and inserting an activated NEA photocathode into the gun for operation. Like the gun, the loadlock also has an excellent vacuum and has its own ion and NEG pumps. During operation, the loadlock, which is at the same potential as the cathode, is supported by an insulating G-10 cylinder mounted on the grounded main flange of the gun.

A vacuum-ready gun must be high-voltage conditioned before it is ready for operation. One of the key advantages of using the loadlock was that a sacrificial cathode could be used for the conditioning process — a process that often caused permanent damage to a GaAs cathode. The conditioning was done in a 1×10^{-7}–1×10^{-6} Torr N_2 ambient by gradually increasing the high voltage until the dark current dropped to below 50 nA at 120 kV. Finally,a strained GaAs cathode was activated and installed in the operation-ready gun. During operation, the GaAs cathode is cooled to about 0 °C for improved QE lifetime, and its QE is monitored with an optically isolated nanoammeter that measures exclusively the cathode current. The gun is equipped with Cs channel dispensors so that Cs may be applied to the cathode when needed.

3.3 Injector

The optics and vacuum designs of the injector downstream of the gun are crucial for reliable gun operation. Using sensitive detectors, beam loss is kept below 0.1% in the first meter and below 1% in the first 3 meters to minimize electron-stimulated gas desorption. A 38° magnetic bend 1 m downstream of the gun isolates the cathode from reflected or reverse accelerated electrons. Immediately following the gun, a differential pumping section employing high-speed ion and NEG pumps effectively minimizes vacuum cross talk between the gun and the injector where the vacuum is three orders of magnitude worse. In addition, the injector is designed to allow for rapid gun swap (about 1 day).

4 Source Performance

Since the spring of 1992, the SLAC polarized electron source has provided high quality polarized electron beams for many colliding beam and fixed target physics runs for about 30 months. The overall operating efficiency exceeded 95%, while the actual accelerator down time due to the source was minimal as much of the source maintenance work coincided with other accelerator work.

Operating the polarized electron source was easy. Various feedback loops helped maintain the stability of the beam intensity out of the gun and the beam orbit in the injector. The only task necessary to perform on the gun during operation was to periodically apply a small amount of Cs to the cathode (a procedure commonly referred to as cesiation) to keep the QE within an optimal operating range. Cesiations were performed remotely by operators through the SLC control program, and took about 20 min to complete including machine recovery. Periodic flashlamp changes that took 4 hours to complete constituted the only routine maintenance work on the Ti:sapphire laser systems. The frequency of flashlamp changes was about once in every 2–3 months for the Nd:YAG lasers and about once in every 10–20 days for the flashlamp pumped Ti:sappire laser.

The operating characteristics of the source for the 1994–5 SLC physics run are summarized below: total physics run time, 10 months; beam intensity at source, $5\text{–}8\times10^{10}$ electron/pulse; beam intensity jitter at source, 0.5–1%; average electron beam polarization at interaction point, 80%; typical QE at 845 nm, 0.1%; QE lifetime, 1200 → 300 hr; cesiation cycle time, 4 – 5 days; total number of cesiations, 54; dark current at 120 kV, <15 nA; and source efficiency, 99%. It should be mentioned that for the majority portion of the run, the QE was intentionally kept from reaching its maximum to keep the polarization as high as possible. Otherwise, both the QE lifetime and cesiation cycle time would have been longer. The most noteworthy is that a single activation at the beginning of the run was sufficient for the cathode to last the whole 10-month period!

5 Conclusion and Outlook

The SLAC polarized electron source is a high-intensity, high-polarization source for accelerators with an operating efficiency approaching that of a conventional source based on a thermionic-cathode gun. It is the result of several years of extensive research and development in the areas of ultrahigh vacuum, high voltage operation, GaAs and related photocathodes, and lasers. Its successful operation has raised the prospects of developing a polarized electron source [21] for the next generation of linear colliders, such as the SLAC Next Linear Collider (NLC) [22]. The NLC is designed to collide up to 90 bunches of ≥ 80% polarized electrons with an interbunch spacing of 1.4 ns with an identical bunch train of unpolarized positrons. The single bunch intensity at the electron source is required to be as high as 2.5×10^{10} electron/bunch with a peak current in excess of 5 A.

A modified Nd:YAG pumped Ti:sapphire laser system based on the SLC version is expected to produce an adequate muti-bunch laser pulse to drive a photocathode gun. As the single bunch intensity requirement for the NLC is less demanding than that of the SLC, the present SLC-type gun may serve as a baseline version for the NLC gun. The SLAC inverted-structure gun [23], in which the cathode electrode is supported by insulators residing inside the grounded gun body, has the advantage of a compact structure and simplified high voltage operation, would be a natural upgrade. However, the long time scale of the charge limit memory effect associated with the strained GaAs cathodes presently employed will prevent it from producing the >100 ns bunch train with the required intensity. Only the more highly doped cathodes (i.e., with a doping density of at least 2×10^{19} cm^{-3}), whose polarization performance is considerably worse, appear capable of the NLC-type charge production [21].

The SLAC 100 nm strained GaAs cathode may be improved in two ways. By protecting the active photoemission layer with a thick As cap layer, the surface NEA properties are expected to be significantly improved. This should boost the QE of the photocathode, which should in turn minimize the impact of the charge limit effect, or possibly even render it irrelevant. Also, using a modulated doping scheme, i.e., high doping ($\geq2\times10^{19}$ cm^{-3}) in a thin, say 5 – 10 nm, surface layer and low doping ($\leq5\times10^{17}$ cm^{-3}) in the rest of the active layer, the memory effect can be minimized while still retaining the high polarization capability of a low-doping cathode. It is expected that continued effort in GaAs photocathode R&D will yield a GaAs-type photocathode that meets both the NLC polarization and intensity requirements. Surely, it appears that a polarized electron source for the NLC is within reach.

Acknowledgments

We thank all of those at SLAC who have made important contribution to the SLAC polarized electron source.

Refernces

1. E.L. Garwin, *et al.*, Helv. Phys. Acta **47**, 393 (1974).
2. G. Lampel and C. Weisleuch, Solid State Commun. **16**, 877 (1975).
3. C.K. Sinclair, *et al.*, AIP Conf. Proc. **35**, 426 (1976).
4. C.Y. Prescott, *et al.*, Phys. Lett. **77B**, 347 (1978).
5. R. Feder, *Polarized Electrons in Surface Physics*, World Scientific Publishing Co., 1985.
6. SLC Design Handbook (December, 1984).

7. D.C. Schultz, *et al.*, "Polarized source performance in 1992 for SLC-SLD", Proc. of *the 10th Intern. Symp. on High Energy Spin Phys.*, Nagoya, Japan, 1992, p. 833.
8. Details on the Stanford linear accelerator polarized electron source can be found in R. Alley, *et al.*, SLAC-PUB-6489, Nucl. Instrum. and Meth., in press.
9. R.L. Bell, *Negative Electron Affinity Devices*, Oxford University Press, 1973.
10. G. Fishman and G. Lampel, Phys. Rev. B**16**, 820 (1977).
11. T. Maruyama, *et al.*, Phys. Rev. Lett. **66**, 2376 (1991); T. Nakanishi, *et al.*, Phys. Lett. A**158**, 345 (1991).
12. T. Omori, *et al.*, Phys. Rev. Lett. **67**, 3294 (1991).
13. T. Maruyama, *et al.*, Phys. Rev. B**46**, 4261 (1992).
14. H. Aoyagi, *et al.*, Phys. Lett. A**167**, 415 (1992).
15. Spire Corporation, Bedford, Massachusetts, 01730, USA.
16. T. Saka, *et al.*, Jpn. J. Appl. Phys. **32**, 1837 (1995).
17. Y. Kurihara, *et al.*, Jpn. J. Appl. Phys. **32**, 1837 (1995).
18. For details, see M. Woods, *et al.*, J. Appl. Phys. **73**, 8531 (1993); H. Tang, *et al.*, Proc. of *the 4th European. Part. Acc. Conf.*, London, England, p. 46 (1994).
19. A. Herrera-Gomez and W.E. Spicer, Proc. of *1993 SPIE Intern. Symp. on Optics, Imaging and Instrumentation*, San Diego, 1993, p. 51.
20. R.A. Mair, *et al.*, Phys. Rev. Lett., to be published.
21. H. Tang, *et al.*, SALC-PUB-95-6585, Proc. of *the 11th Intern. Symp. on High Energy Spin Phys.*, Bloomington, IN, USA, September, 1995.
22. T. Raubenheimer, *et al.*, "Parameters of the SLAC Next Linear Collider", Proc. of the 1995 Part. Acc. Conf., Dallas, USA, to be published.
23. M. Breidenbach, *et al.*, Nucl. Instrum. and Meth. A**350**, 1 (1994).